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MANIPULATION OF CHAMISE BRUSH FOR DEER RANGE IMPROVEMENT[1]

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Chamise brushlands in California occupy about 7,300,000 acres (Sampson, 1944). They are highly variable in plant species, soil fertility, degree of slope, availability of drinking water, and general suitability for deer. These brushlands are valuable mainly for watershed and game; however, some are grazed by livestock and others are being cleared for farming. Wildfires are frequent and widespread. These are typical items that must be considered wherever brushland management is undertaken for game. It is also wise to keep in mind that each brushland is different, and requires a plan all its own.

Studies, over a period of several years, have been made on the possibilities of managing chamise brushlands for deer. The investigations were centered in Lake County, but with certain portions widely scattered throughout the coastal ranges. Two objectives were foremost: (1) to determine the extent to which deer populations increase with brush cover manipulation; and (2) to study and test various methods of manipulating chamise brush for maximum deer use and sustained yield of forage.

The California Department of Fish and Game, aware of this need, contracted with the University of California for the research, with funds provided by Federal Aid in Wildlife Restoration Act, Project California 31-R. Details have been published by Biswell *et al.* (1952) and by Taber and Dasmann (1958).

CONDITIONS OF CHAMISE BRUSHLANDS IN LAKE COUNTY

In general the chamise brushlands in Lake County comprise two cover types, one in which chamise *(Adenostoma fasciculatum)* predominates, and one containing a mixture of broadleaf shrubs and trees, known as mixed chaparral (Figure 1). The chamise occurs mainly on south-facing slopes and drier sites while the mixed chaparral is found on the more mesic, north-facing exposures and in ravines. This intermixture of types and species is particularly favorable for deer since it provides a wide variety of forage as well as greater seasonal choice. The intermixture of browse plants in Lake County is probably as favorable for deer as most chamise brushlands in other parts of the state. Some brushlands are so nearly pure chamise that they furnish relatively poor browse.

The dominant shrubs and trees over the study areas in Lake County were chamise, interior liveoak *(Quercus wislizenii)*, Eastwood manzanita *(Arctostaphylos glandulosa)*, scrub oak *(Q. dumosa)*, California

[1] Submitted for publication April, 1960.

FIGURE 1. Typical chamise brushland in Lake County. Chamise predominates on the south-facing exposures and many shrubs and small trees grow on the north-facing exposures.

laurel *(Umbellularia californica)*, toyon *(Photinia arbutifolia)*, wedgeleaf ceanothus *(Ceanothus cuneatus)*, wavyleaf ceanothus *(C. foliosus)*, deerbrush *(C. integerrimus)*, Stanford manzanita *(A. stanfordiana)*, yerba santa *(Eriodictyon californicum)*, poison oak *(Rhus diversiloba)*, western mountain mahogany *(Cercocarpus betuloides)*, and chaparral pea *(Pickeringia montana)*, approximately in that order of abundance. Some of these, of course, are more palatable and nutritious than others, and some can well be considered "weeds." The more palatable species are chamise, wedgeleaf ceanothus, wavyleaf ceanothus, deerbrush, and western mountain mahogany. The least desirable are the manzanitas and yerba santa. The others might be considered intermediate in palatability. Grasses and forbs, both annual and perennial species, are many. In dense, mature brush these are sparse, but in openings they provide abundant nutritious forage in the winter and spring months.

It is generally known that a majority of chamise brushland soils are low in fertility; also, many brushlands are extremely rough in topography. In the study areas, soils on the south exposures are mainly less than 12 inches deep, while those on the north exposures are generally 12 to 24 inches deep. The slopes average 20 to 25 degrees, with perhaps 50 percent of them too steep for land tilling equipment or bulldozers (Figure 2). Ravines are numerous, many with seeps that furnish year-long drinking water for deer. Precipitation averages 28 inches, practically all as rain between September and April, inclusive. The

FIGURE 2. Some chamise brushlands are rugged and are too steep for landtilling equipment or bulldozers.

summer months are extremely dry. The mean annual temperature is about 57° F., the extremes varying generally from about 20° to 110°. The same general pattern of rainfall and temperatures characterizes all chamise brushlands in California. The brushlands usually occur where the precipitation is between 14 and 40 inches. In areas of annual rainfall up to 14 inches, the chamise becomes open and desert-like in appearance; with rainfall over 40 inches, it generally gives way to forest growth. In areas receiving between 14 and 40 inches of rainfall, the soil is apparently more important than climate in delimiting chamise brushlands.

The Columbian black-tailed deer *(Odocoileus hemionus columbianus)* is found in abundance in Lake County chamise brushlands. This game animal is found all through the Coast Range brushlands from about Santa Barbara County north to the Oregon line (Taber and Dasmann, 1958). Over this entire area, deer are usually resident, and occupy essentially the same grounds all year. However, they may shift around somewhat, depending on food supply and weather. For example, the deer may appear under oaks on nearby ranges when acorns are dropping in the fall, or on grasslands in winter when the herbs are coming up, or in nearby fields and orchards during the hot, dry summer months, but usually such movements are for short distances and are not measured in miles.

BRUSH COVER MANIPULATION AND GAME POPULATION

Deer have certain environmental requirements for optimum production. Among these are: year-long forage that is palatable and nutritious; cover for escape and perhaps for resting; and drinking water. An absence of any one of these factors may make an area largely, or

FIGURE 3. Chamise brushland on Glenn Keithly ranch in Lake County opened by control burning. The combination of openings with herboceous forage and patches of unburned dense brush provides ideal deer range conditions.

FIGURE 4. Ideal deer range in Scotts Valley, Lake County. The pattern of openings was largely created by control burning. Most ravines have seeps that furnish year-long drinking water for deer.

FIGURE 5. Opened brushland on Ora Ranch. Many of the sprouts that came after control burning are browsed down so that sprout regrowth is easily available to the deer.

even entirely, unsuitable for deer. With these requirements in mind, studies were designed to compare three cover areas: (1) opened brush (Figures 3 and 4), consisting of small, burned patches here and there, seeded to suitable herbaceous species; (2) heavy brush protected from fire (which served as a control); and (3) an area burned by wildfire. The size of each area was about 1,000 acres. These cover conditions are referred to in the following as opened brush, heavy untreated brush, and wildfire burn.

Forage Availability

Forage available to the deer was quite different under each of the three conditions of brushland. In the opened brush many herbaceous plants were present, both grasses and forbs. In addition, many of the shrubs were browsed down so that sprout regrowth was easily available to the deer (Figure 5). Edges of remaining patches of heavy brush provided an extensive strip along which the deer could browse.

In the area of heavy untreated brush there was little in the way of herbaceous plants, and on the north-facing exposures many of the shrubs and trees were tall and out of reach of the deer. Certain shrubs that normally appear after fire and persist for several years were very scarce, including wavyleaf ceanothus and yerba santa. More acorns were generally available to the deer in the heavy brush area than in either the opened brush or wildfire burn.

In the area of wildfire burn, an abundance of sprouts was available within a few weeks after the fire. This usually happens unless the fire occurs after about the middle of September, in which case sprouting may not be profuse until the next spring. A small quantity of grasses and forbs grew naturally in the wildfire burn, which was not seeded after the fire. For the most part, browse was plentiful and nutritious the first year but gradually declined in quality thereafter as the plants grew back toward maturity. Maturity is reached within 12 to 15 years where browsing is light.

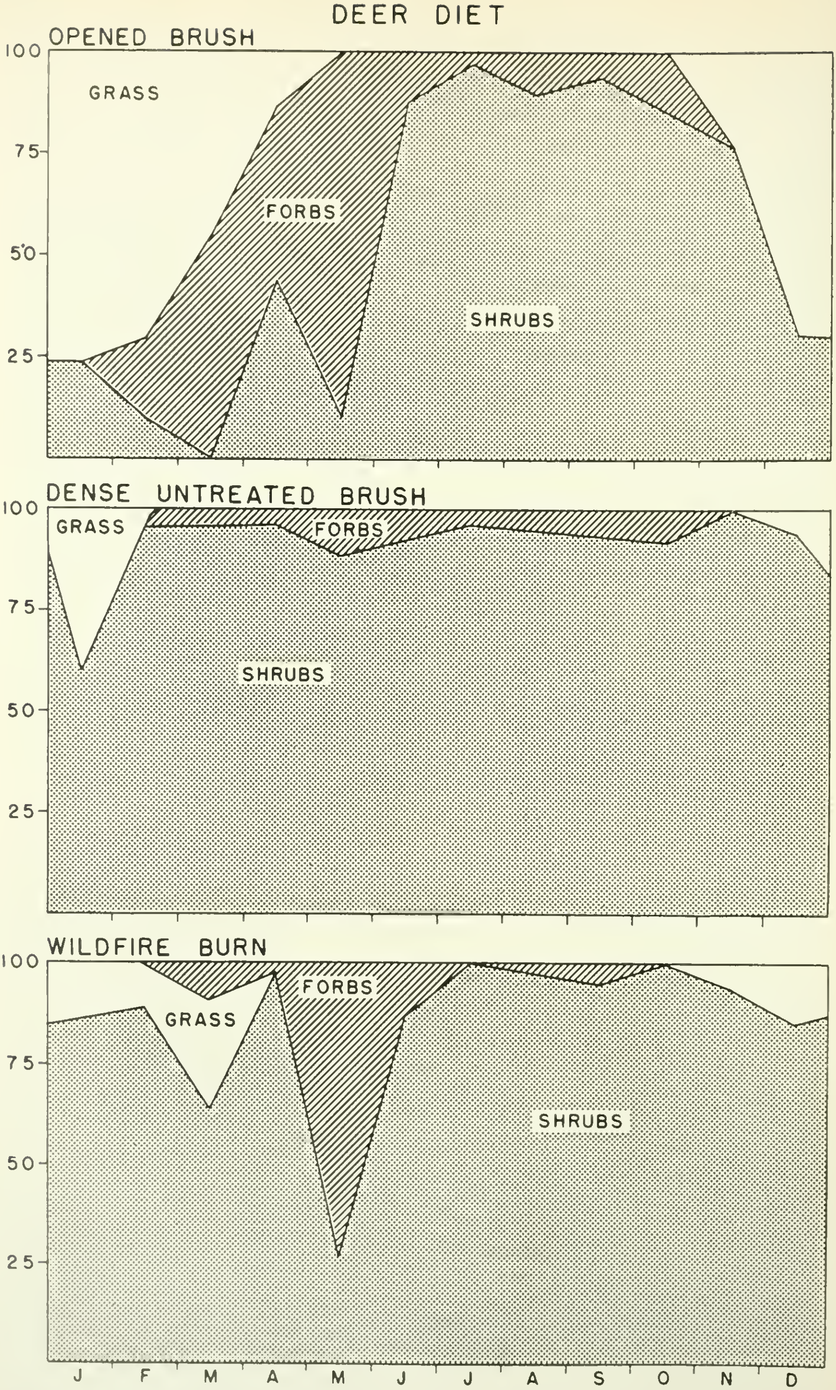

FIGURE 6. Comparative diets of deer on opened brushland, an dense untreated brush, and on wildfire burn. Grasses and forbs constitute a favorite winter and spring food item where available, but shrubs are the primary source of food in summer. (Adapted from Taber and Dasmann, 1958.)

Food Habits of Deer

Information on the food habits of deer on the three areas was gained largely by analysis of stomach samples. Results are shown in Figure 6. For the whole year, grasses and forbs compromised more than 40 percent of the diet in the opened brush. These plants constitute a favorite winter and spring food item. In dense, heavy brush the grasses and forbs were much scarcer on the ground, and made up only about 5 percent of the diet. Here the deer were more or less forced to feed on dormant brush which was very low in nutritive value. On the new wildfire burn the grasses and forbs were more plentiful than in the heavy brush, and accounted for about 14 percent of the deer diet. In all areas the grasses and forbs were preferred in January, February, and March, and until the shrubs began to put out new growth in April.

Chamise was the most important plant on all ranges from the standpoint of volume taken. Other forage shrubs of much importance were interior liveoak, scrub oak, poison oak, deerbrush, toyon, California laurel, and western mountain mahogany—largely dry-season foods—and yerba santa, eaten in late winter and early spring before new browse appears. Many other plants were selected, sometimes in quantity, but on the average they were less important than those listed above.

The deer have rather definite feeding areas at different seasons of the year, and their selection of foods at any season is limited somewhat by the plants growing in a given area. In the heat of summer, the deer feed mostly on north-facing slopes and in stream beds. At that time, of course, the diet is high in north-slope and stream bed vegetation. In winter the deer feed on the warmer, south-facing slopes. There they take grasses and forbs, chamise, and perhaps yerba santa.

Quality of Deer Forage

As mentioned above, deer are selective in their feeding habits. Usually they take young growth which is high in protein, moisture, and sugars, and they like acorns in the fall, if available.

Samples representing deer diet were taken from each of the three range conditions and were analyzed for protein. For a full year the averages for protein content were as follows: opened brush, 14.4 percent; heavy untreated brush, 9.2 percent; wildfire burn 16.7 percent (Taber and Dasmann, 1958). All three range conditions showed similar seasonal patterns, with the diet highest in protein in spring and lowest in the fall after the shrubs had ceased growing and the grasses and forbs were mainly dry. For the heavy untreated brush, the protein content was 7.0 percent or less from September to December, inclusive, and reached a low of 5.1 percent in November. The lowest for the opened brush was 9.2 percent in August. In general the condition of the deer followed the protein level of the forage, being high in spring and summer, declining through late summer and fall, and reaching a low point in late winter. Deer condition became lowest of all in the area of dense heavy brush. Taber (1956) suggested three reasons for the higher protein content of deer diet in the opened brush as compared with that of the heavy untreated brush: (1) the higher proportion of high protein, herbaceous forage in winter and early spring in the opened brush diet; (2) the shrubs on the opened area kept within reach of deer through

browsing pressure so that the leaves, which are higher in protein than the stems, can be selected; (3) browsing of hedged shrubs over a long period of time, stimulating regrowth which is high in protein.

Plant Successions

Plant populations in brushlands are in a constant state of continual change. Some of the changes may be favorable to deer but others are not. Furthermore, some of the variations are natural; others may be induced. In habitat management work it is important to be able to predict the course of changes and know how to induce those desired. It is also important to know the effect that certain successions have on range grazing capacity. But first of all, one should know the ecology and importance of each species on the range.

Among other things, successions take place because (1) some species grow taller than others and are better able to compete; (2) some are preferred food items of deer and are suppressed by heavy browsing; (3) others are scarcely eaten and are even favored by the browsing and suppression of neighboring plants; (4) some species reproduce from both sprouting and seed after fire while others reproduce only from seed.

Fire is one of the more important factors governing plant populations in brush fields. The time and frequency of burning play important roles in plant successions. Fire stimulates seed germination of most brushland shrubs and prepares a seedbed favorable for new seedlings. Fire also initiates crown sprouting of most shrubs; exceptions in the study areas were wedgeleaf and wavyleaf ceanothus, and Stanford manzanita, all of which reproduce only from seed.

After fire in dense brush, seedlings appear by the thousands in springtime. Germination seems to be greatest from fall burns and least from fires that occur about March 15 to April 1. After about April 1 the seedlings do not appear until the following spring. By that time the seedbed has become more compacted and herbaceous species have increased enough to offer competition to new brush seedlings. Futhermore, sprouts from stumps have grown enough to compete also with the new brush seedlings.

Seedlings of some shrubs, such as chamise and yerba santa, seldom become established without fire. Most of the shrubs are vigorous sprouters, except deerbrush which is a weak sprouter. Wedgeleaf and wavyleaf ceanothus and Stanford manzanita are non-sprouters. Yerba santa reproduces from seed after fire and also by sprouting if old plants are present. Later, this species reproduces and spreads by shoots from horizontal, underground stems. Because the plant reproduces in this way and is not a preferred species, it increases where other shrubs are reduced by heavy browsing. This shrub is not browsed except in winter when other, more preferred species are scarce. Some shrubs, such as western mountain mahogany and wedgeleaf ceanothus, produce seeds that germinate readily without fire.

Frequent fires can reduce the abundance of certain valuable non-sprouting species, such as wedgeleaf ceanothus. When a second fire occurs before a new crop of seeds is produced, this plant can be nearly wiped out. Thus, frequent fires favor sprouting species.

Some species appear after fire and later give way to taller and longer lived species. For example, seeds of wavyleaf ceanothus germinate with fire, but the shrub grows to a height of only 18 to 24 inches. Soon it is overtopped by taller species, and disappears from the stand until the next fire, after which dormant seeds germinate. In opened or heavily browsed brush, where other shrubs are suppressed, this species may remain in the stand for many years. Yerba santa is another species that disappears when the brush becomes heavy and dense. In dense brush this species disappears almost completely within about 20 years. With longer protection other species begin to disappear. For example, in a one-hundred-year-old brush stand in San Benito County much of the wedgeleaf ceanothus in the stand had died leaving mainly chamise.

Heavy browsing of sprouts of preferred species after fire can kill individual shrubs. Species heavily browsed, and frequently killed, on the experimental area were western mountain mahogany, deerbrush, and California laurel. Seedlings are not so easily killed as are plants that have stump sprouted.

Deer Populations

A census of deer on the different areas was usually taken at least twice each year, first by the pellet-group count method and later by the sample-area count method. Counts in opened brush gave a summer population density of about 98 deer per square mile after the initial brush manipulation treatment. This rose to 131 the second year, and then dropped to about 84 the fifth and sixth years, at which point the population presumably stabilized. Measurements in the heavy untreated brush gave a summer density of only 30 deer per square mile. The wildfire burn, which was dense brush before it burned, showed 120 deer per square mile the summer following burning. Some of this increase was due to influx from the areas immediately surrounding the burn. As the wildfire burn area grew older, the population fell to 106 the second year, 52 the third, and 44 the fourth. Eventually it reaches the same status as the heavy untreated brush, probably in 12 to 15 years. Usually wildfire burns recover rapidly because deer numbers are not sufficient to suppress the sprouts.

Fawn Production

Studies on collected does indicate that fawn production is governed largely by ovulation rate. However, ovulation rate does not tell everything because successful births and nursing are also important. Ovulation rates in adult does were approximately as follows: on opened brush range, 175 percent; on heavy untreated brush, 82 percent; on wildfire burn, 140 percent. Figures of fawn production correspond closely to those of ovulation rate but were lower, of course. The following average values for fawn production seem representative: in opened brush 145 fawns to 100 does; in heavy brush, 71 fawns to 100 does; in wildfire burn, 115 fawns to 100 does.

Deer Weight Differences

It was noted that opened brush and wildfire burns offered summer diets of higher quality than that offered by the heavy untreated brush. The deer weights showed essentially this same relationship, those of

the deer in the wildfire burn being highest and those of the deer in the dense brush, lowest. The difference between the extremes was about 13 pounds.

The peak weights for bucks in the opened brush and wildfire burn were reached in July. From this point they declined. Bucks in dense brush retained their fall condition better than did bucks on other ranges, probably because their acorn supply was greater. The advantage conferred by the acorn crop is short-lived, however. From an October high of nine pounds above average, the buck weights fell rapidly to a February low of 39 pounds below average. Their weight when on the wildfire burn dropped low in February too, probably because of a shortage of grasses and forbs. The bucks from opened brush with nutritious grasses and forbs maintained their condition well through the winter.

Does followed much the same condition cycle as bucks with the exception that peak condition for does was reached earlier in the summer, and in winter the drop in condition in heavy brush was not so pronounced as in the bucks. The exact reason for this is not known.

Resident Small Game

Although the studies were concerned chiefly with deer, observations were made of the small game populations as related to brush manipulation. The density estimates given below are based on strip-counts and observations for quail (*Lophortyx californica*), pellet counts for the California jackrabbits (*Lepus californicus*), and general observations for brush rabbits (*Sylvilagus bachmani*) and mourning doves (*Zenaidura macroura*). Valley quail are definitely encouraged by opening dense brush. In the openings, the quail find abundant herbaceous forage and seeds with cover nearby. Late summer populations of 250 per square mile were found in the opened brush. However, in the heavy brush and wildfire burn the number was only about 100 per square mile.

California jackrabbits also reach their greatest densities in opened brush, where their number fluctuated between 10 and 45 per square mile. The highest counts were made in late summer. In heavy untreated brush the number was low, only about one per square mile. In the wildfire burn the number varied from five to ten per square mile.

Brush rabbits were numerous in the heavy untreated brush, and in and around islands of heavy brush in both the opened areas and in the wildfire burn.

Mourning dove populations were highest in the opened brush, second in the wildfire burn, and very low in the heavy untreated brush.

It seems evident that in the opened brush the generous amounts of herbaceous vegetation, along with the edge effect supplied by the scattered clumps of brush, encourage the build-up of most resident small game species (Burcham, 1950). In the opened brush one finds not only the dense populations of most small game, but also cover which is most suitable for upland hunting. Even species such as the brush rabbit, which seem to be more numerous in the heavy brush than in the opened brush, may be hunted more successfully in the latter areas.

METHODS OF MANIPULATING CHAMISE BRUSH

In the light of the foregoing results, it would seem that the general objective in management of chamise brushlands for game should be to reduce the brush cover in spots and introduce palatable herbaceous species for use in winter and early spring.

Manipulation can completely convert brush to grasses in spots, or thin the shrubs in spots to enable grasses to grow also. In the first case, browse is provided along the edges of openings, and grasses and forbs are abundant for winter and spring use. In the second case, browse comes from the scattered shrubs in the openings as well as from the edges. The latter should provide a greater total quantity of browse than the first method. The principal advantage of the first method is that the grasses in the open spots grow denser and therefore more completely cover and protect the soil.

Opening dense chamise brushland provides a desirable interspersion of food and cover. Once chamise brushlands are properly opened and the growth of herbaceous species is encouraged, good management should keep them productive over a long period of time with a minimum of further disturbance.

Methods studied in opening chamise brushlands were burning and livestock grazing, mechanical means, and chemical treatment. Seeding

FIGURE 7. Control strip burning in May in chamise. The fire was lit at the base of the slope so that it burned uphill. It did not spread to the sides, and went out at the top. The burning was done on a clear day when the humidity was 27 percent. Grasses outside of the brush area were green.

of desirable forage plants should generally be combined with any of these methods to better establish a suitable cover of herbaceous species soon after the brush is removed. Most of the chamise brushlands opened thus far have been by a combination of methods. Although livestock grazing is of little importance by itself, it can be a powerful tool for controlling chamise brush when used in combination with burning or mechanical means.

Burning and Grazing

From the standpoint of game management, either spring or late fall burning has proved satisfactory in opening chamise. Spring burning, before the grasses outside of the brush areas become dry, is relatively easy, with good fire control. Any time that the humidity is around 25 to 30 percent and the wind is calm it is usually possible to light a fire at the bottom of a slope and have it burn uphill (Figure 7). Usually the fire does not spread to the sides and will go out at the top of the slope (Figure 8). Areas of decadent brush, containing considerable dead material, will burn easiest. In such areas, firing should be started when the humidity is relatively high. Late fall burning is slightly more hazardous than spring burning, and usually requires more elaborate preparations. Information on techniques in burning may be found in Arnold, *et al* (1951). Flame throwers are effective in setting fire in spring and late fall burning. The best way to learn about the use of fire is through experience in the field under the instruction of someone competent. It requires considerable planning, care, effort, and patience.

Summer burning in chamise brushlands for game is not recommended because of the difficulty and expense involved in fire control.

Studies have not gone far enough to determine precisely whether most of the burning for game in chamise brush should be in the spring or late fall, or whether a combination of the two seasons should be used. After spring burning, sprouts will appear within 3 or 4 weeks and supply a highly nutritious forage for deer during the dry summer

FIGURE 8. Portion of Cow Mountain recreation area in Lake County where strip burning is being done in the spring months to improve browse and cover conditions for deers.

months. However, studies thus far indicate that few brush seedlings appear on spring burns, especially where burning is done after the first of April. This would mean that sprouting species, such as chamise and manzanita, are favored over nonsprouters, such as wedgeleaf ceanothus. If this is borne out by further studies on burns made before seed maturity, it may be found that the composition of the brush cover for deer may be adversely affected by spring burning. Some fall burning may then be necessary to provide young plants of wedgeleaf ceanothus, wavyleaf ceanothus, and other valuable nonsprouting browse plants.

Control of sprouts after burning is an essential step in the opening of dense chamise brushlands. Both measurements and observations indicate that deer will probably be effective in suppressing sprouts through browsing. Sheep can also be used in some places to good advantage, especially in large burns where the deer population is inadequate to suppress the browse plants. Without utilization, chamise sprouts will attain an average height of nearly 20 inches the first summer after fall burning, and interior live oak will reach 30 to 40 inches. Thus, unless the sprouts are browsed they soon become useless as food for game. Deer and sheep are effective in controlling sprouts by killing some of the plants the first season following burning.

The extent to which deer and sheep may suppress sprout growth is indicated by measurements of chamise sprouts under various conditions of grazing use and in protected areas on two-year-old burns. Even light browsing by deer considerably suppressed the growth of sprouts. A majority of the sprouts browsed lightly by deer averaged about 18 inches in height while those protected by fenced exclosures averaged between 22 and 32 inches.

Close utilization by deer may kill many of the sprouts the first year following fire. This results in opening the brush. Some sprouts may be killed the second year, but few, if any, are killed after the sprouts are five years or more old. After the chamise plants are 6 to 8 inches tall, the stiff stems keep the deer from grazing so closely as to kill the plants.

Burned spots should usually be small—5 to 10 acres—in order to form as much edge as possible. The acreage to be burned should be decided upon before burning is started. If the deer population is dense or if a band of sheep is available to control sprout growth the first year, the acreage burned may be fairly large. In general, however, deer populations in heavy brush areas are fairly low, and the burns should be kept small. Spot burns of about 5 acres scattered here and there are probably sufficient for initiating a program of managing chamise brushlands. The spots should be scattered evenly over the whole area, rather than clumped. It is wise to proceed in stages, so that the deer can keep up with the brush sprouting. In the second or third year it might be desirable to make new burns in the region where deer use has been heavy. If the deer are effectively opening the brush, it might be well to go rather fast; but if not, proceed slowly. This procedure should continue until the desired amount of opening has been accomplished. In the end perhaps as much as 75 percent of an area can be converted to small open spots.

FIGURE 9. Mechanical manipulation of brush to improve conditions for deer. The brush was pushed over in February, with the bulldozer blade about six inches above the soil. The chamise is sprouting vigorously. Several seedlings of wedgeleaf ceanothus were found. Photograph taken on July 14, 1952.

FIGURE 10. Taken on Cow Mountain recreation area in Lake County looking across Buck Canyon where open spots and trails were created by use of bulldozer and heavy disk cutter.

Mechanical Manipulation of Brush

In suitable areas chamise brushlands may be opened mechanically by heavy disking or by pushing the brush over with a bulldozer blade six inches above the soil (Figures 9 and 10). Pushed-over brush need not be burned. There are several advantages to opening chamise brushlands mechanically. In the first place, a residue is left on the soil, which is helpful in erosion control. The residue protects reseeded grasses against frost heaving and intense heat and drying by the sun. If pushing over brush along ridge tops enables one to start herbaceous vegetation more easily, the practice may provide an added seed source for revegetation when slopes below are burned. This is an important point, for seeding failures are common in burned chamise brushlands, and any assurance of a continuing seed supply is invaluable. Mechanical means can be used in areas where it is too dangerous to attempt burning. Another advantage in mechanical control is that patterns of interspersion of brush and grass can be obtained without difficulty.

The chief disadvantages of mechanical removal are that the cost may be greater than strip burning in the spring, and that many areas are relatively inaccessible to mechanical equipment. Pushed-over brush creates quite a fire hazard because much of the brush is killed. On the other hand, heavy disking tends to incorporate the residue into the soil, and the fire hazard is reduced.

Chemical Treatment

Where the objective is complete conversion to grasses in spots, chemicals are very useful (Leonard and Carlson, 1957). After an area has undergone controlled burning, sprays should be applied to the sprouts and seedlings the following spring after the seedlings have emerged and before the soil is completely dry. Ground applications are more effective than those by airplane. However, ground applications may be very difficult or even impossible in some places because of rough topography. Some species such as interior liveoak and coffee berry (*Rhamnus californica*) may require two or three applications for complete kill.

Tests were made to learn whether chemical sprays could be applied in strips on large wildfire burns to retard development and maintain the brush cover in varying stages of development. This proved possible, but at the same time many of the preferred shrubs were killed. Therefore, the method seems impractical at present. As new knowledge is gained, it may become possible to develop and select sprays to kill certain undesirable species and not appreciably harm the better ones.

Almost any brushland range has certain species that are highly preferred and others that are scarcely touched. If the range is let alone, the better species are gradually weakened and killed, and the poorer ones are free to thrive. One way to break this trend is for the manager to discourage the undesirables deliberately with chemicals. As mentioned above, some species will require two or three treatments for complete kills. This method is expensive.

FIGURE 11. Taken on Perrini Ranch in Lake County where an excellent stand of soft chess was obtained from reseeding after fire. This species is well adapted to poor sites. On the better sites, and particularly above 2,000 feet elevation, perennial grasses did well.

RESEEDING CHAMISE BRUSHLANDS

When chamise brush has been removed by burning or disking, reseeding to desirable forage species is advised (Figure 11). The new grasses furnish forage for the deer in winter and spring; help protect the soil against erosion; and provide competition to the many brush seedlings that come after fire (Schultz and Biswell, 1952; Schultz *et al.*, 1955). In other words, the grasses aid in opening dense brushlands. The grasses also may be useful for a reburn if necessary. The County Farm Advisor should be consulted for advice on which species to reseed on each site.

Several annual and perennial species were used in Lake County with good results. On the poorest sites, soft chess (*Bromus mollis*) proved particularly useful and on the better sites, and above 2,000 feet, Hardinggrass (*Pharlaris tuberosa*), perennial ryegrass (*Lolium perenne*), and tall fescue (*Festuca arundinacea*) did well. In some areas legumes may prove useful (Love and Jones, 1952).

In general, seedings made about the middle or latter part of September, shortly before the start of fall rains, were the most successful. Seedings made in the spring or summer after spring burns were not as successful as those made in late summer or early fall. Seedings made in February were complete failures.

DISCUSSION

Deer management is concerned with two main interrelated objectives: the development and improvement of the habitat, and the control of hunting. This particular study was concerned with the first of these objectives.

It is clear that food quality is an important factor limiting deer populations in chamise brushlands. The animals seem to do best when grasses and forbs grow intermixed with palatable shrubs, and when oaks are available to produce acorns for fall use. If a deer lives in an area where all of these are available, it will eat grasses and forbs in the winter and early spring, brush sprouts in the late spring, succulent herbs and brush sprouts in the summer, and acorns with some browse in the fall. The main group of these elements lacking in most chamise brushlands is herbaceous plants.

Many brushlands grow so densely that grasses and forbs are shaded out or have no growing space. In heavy untreated brush, the new green herbaceous growth which is eaten so avidly in January, February, and March, is nearly absent. Consequently, this forage comprises very little of the food of the deer which live in such an area. If deer are forced to eat dormant brush during the winter months they do not thrive so well as those which also eat herbaceous plants.

In late March or early April the shrubs begin to grow and the deer turn to the new, tender, nutritious shoots of those plants. At that time the deer make their most rapid gains in weight. However, not all shrubs are palatable to the deer—some species are much preferred to others. For example, chamise and western mountain mahogany are taken in large quantity in the early summer, while Eastwood manzanita is scarcely touched. Management, therefore, should strive to cultivate or favor the preferred species. In addition some shrubs are tall and the new growth is not available—deer seldom reach up more than four feet for food. Therefore, deer receive little benefit from such browse no matter how abundant or palatable it might be.

Another sort of availability should be considered. Deer like to feed in the partial open, and will spend more time feeding when the shrubs are separate, or at the edge of a patch, than when the plants are growing densely. So forage produced within dense thickets is not as available. Often people do not understand why there isn't enough deer forage when hills are covered with brush. However, many times the shrubs are not the right kind or they are too dense and tall for the deer to use.

Before any brush manipulation is undertaken the game manager must have a clear picture of what he is trying to attain. Knowledge of both the game population and the plant population in the brush area to be manipulated and managed is essential. On the basis of present information, several steps in the manipulation of chamise brushlands are fairly well understood.

1. The success of opening chamise brushlands is dependent upon the presence of at least a few deer in the general locality. A total absence of deer may indicate a lack of water or some other limiting factor.

2. Some brushlands are better adapted to growing grasses than are others. The more productive areas should be selected first—those where there is reasonable assurance that grasses will grow abundantly.

FIGURE 12. Chamise brushland in Lake County, with fire lanes established in preparation for control burning.

3. Whether fire or mechanical means are used in opening dense brush depends largely on the risk of using fire, brush cover conditions, terrain, etc. Where the vegetation is predominantly chamise on south exposures and mixed chaparral on north exposures, spring burning may be done without very high risk. The south-facing chamise slopes can be burned on days of relatively low humidity and with proper wind velocity and direction, from February through May, for then the north-facing slopes of mixed chaparral are not very likely to burn. On quiet days, fires lit at the bottom of the chamise slopes usually go out at the ridge tops (Figure 12). One or two men equipped with flame throwers can usually do the burning. Throughout the period from February through May, there will be many days when it is too moist to burn and others when it is too dry to use fire safely. Where fire is used, permission must be obtained from the District Ranger of the State Division of Forestry.

4. Where chamise brush occupies all exposures, and is of uniform density, the risk of using fire is greater than it is where the type of brush varies with exposure. Where grass borders the brush, burning when the grass is green adds an element of control. However, it may be dangerous to burn at any time when the wind is high and the humidity below 25 percent.

5. Where conditions for burning are hazardous and the terrain is not too steep, mechanical means may be used to open the brush. Usually this method is more costly than controlled burning. Chemicals are necessary where the objective is complete conversion to grasses in the open spots.

6. The extent to which a brush area should be opened depends almost entirely on the deer population present. Where a square mile has less than 10 deer, a half dozen scattered, opened areas, each of about five acres, may be sufficient. Where the deer population is greater than ten

per square mile, a correspondingly larger number of areas should be opened. If the new sprouts are browsed so heavily that a majority of them is killed the first season, then a larger number of spots should be opened the next year. On the other hand, if browsing is light, it is desirable to wait two or three years before additional spots are opened. Approximately 25 percent of the area should be left in well distributed, dense brush as cover for game.

7. All areas cleared of brush should be reseeded to adapted forage plants before the first fall rains. If the reseeding is not done by that time, however, it is still not too late to seed soon after the first rains, but with less satisfactory results. Insofar as possible, species valuable for forage and watershed cover should be used. It is wise to contact the local County Farm Advisor for advice on species to reseed. Where too much area is covered in the initial burn for deer to suppress sprout growth, it may be necessary to reburn in spots to retard sprouts. This should be done two to four years after the first burn, where reseeded grasses still carry the fire. In general, however, as little reburning as possible should be done for this tends to eliminate certain of the valuable non-sprouting species, and may also result in opening the brush too much. Insofar as possible, sprout growth should be retarded by deer browsing, and areas should be maintained in open condition in this way. When areas are properly opened, every care should be taken to avoid wildfires for these are likely to upset the proper interspersion of brush and herbaceous plants, and may not leave enough dense brush cover for deer.

8. In the end, attention should be given to grazing management, especially where animals other than deer use the range. The general objective should be to leave enough grass residue on the ground for an effective watershed cover, and to maintain a high level of fawn production without depletion of range carrying capacity. Where the browse species are properly utilized the grasses are likely to be properly grazed, too. Areas fully stocked with deer will scarcely support any cattle or horses because the additional animals would result in too close grazing. Utilization by sheep is similar to that by deer; where both kinds of animals use the range, proper allowance must be made for each.

9. When the range has been fully developed or improved and the deer population has increased to full range carrying capacity, the second phase of deer management should come into play—that of harvesting the excess deer through control of hunting. It would seem wise that the annual increment be harvested each year in order to keep the herd healthy and to reap the benefits of investments in habitat improvement.

SUMMARY

Studies were made of the extent to which deer populations increase with brush cover manipulation, and of methods of developing and improving brushlands for deer. An opened area of brushland was compared with one of heavy untreated brush as a control, and with another burned by wildfire.

Deliberate opening of chamise brushlands in spots made for a favorable interspersion of grasses and forbs, browse, and cover. Deer populations in summer, in opened brush, were about three times greater than those in heavy untreated brush. Populations in a wildfire burn were about equal to those in opened brush for a few years after the fire but then gradually declined as the brush grew back toward its former mature condition.

The general objective in the manipulation of chamise brushlands for game should be to reduce the brush cover in spots and introduce palatable herbaceous species for use in winter and early spring. Methods for doing this are controlled burning and grazing, mechanical means, such as bulldozing and disking, and chemical treatment. Usually a combination of these methods will serve best. Reseeding to desirable forage and watershed plants should follow in places where brush has been removed by burning and disking.

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DEER MOVEMENTS OF THE McCLOUD FLATS HERDS[1]

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INTRODUCTION

This paper reports on a deer trapping and tagging study that was started in July 1955 and continued through September 1958. The purpose was to observe the movements of migratory deer, which summer on the McCloud Flats in southeastern Siskiyou County, California, and to locate their winter range. Longhurst, *et al.* (1952) indicated that they migrated eastward and spent the winter around Day in Modoc County. However, there were various other opinions as to where these deer wintered. In order to resolve this confusion and to properly manage the deer herds it was necessary to carry out this study.

During the summers of 1955 and 1956, a total of 115 deer were trapped at four locations on the McCloud Flats. All the animals were tagged and 91 of them were belled. The use of bells resulted in the observation of many marked animals that otherwise would have been overlooked.

Sight records of 170 belled deer, five of which were individually identified from their colored tags, plus 29 killed marked deer proved that these deer move from a common summer range to widely scattered winter ranges. Gruell (1958) found that wintering herds are not individually limited to any specific summer locality. Repeated observations of individual deer in this study indicate that in both summer and winter they have a small home range, except when affected by adverse weather. Drought conditions in 1955 revealed that movements occurred readily as the available water was depleted. Possession of water by campers and sportsmen can induce early migration during the dry season.

THE STUDY AREA

Siskiyou County, just south of the Oregon border, has two main floral types. These are of North Coastal influence in the western half, and of Great Basin type in the eastern half of the county. The McCloud Flats is a deer summer range of approximately 2,400 square miles. The area is predominantly flat, ranging in elevation from 4,000 to 5,000 feet. The forests are ponderosa (*Pinus ponderosa*) and lodgepole pine (*P. contorta*) climax types that are common in areas of the Great Basin. A large part of the ponderosa pine forests was logged over in the early 1900's, and now has an understory of bitterbrush (*Purshia tridentata*),

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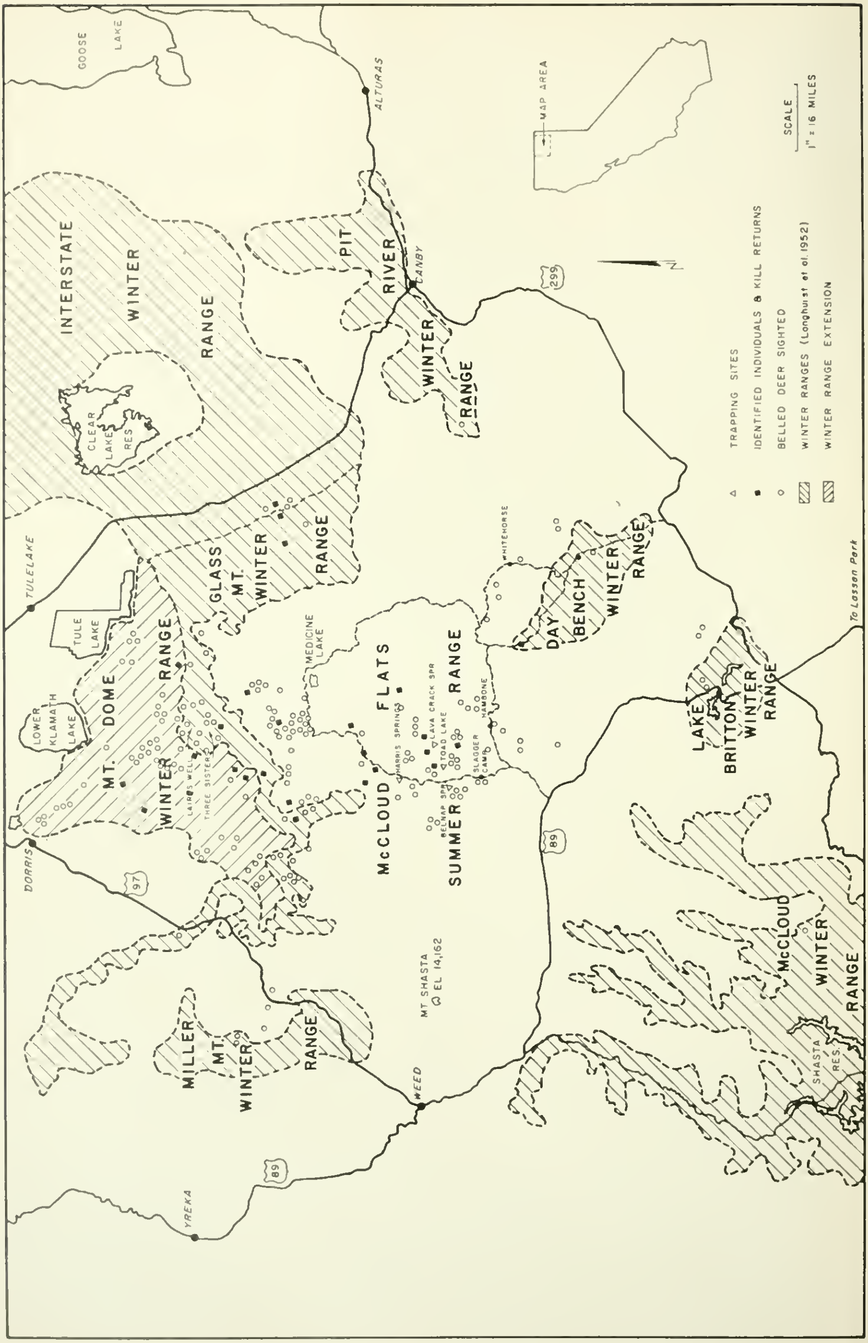

FIGURE 1. Ranges involved in this study with movement data of individual deer. (Correction: Between Weed and Yreka the highway is U.S. 99.)

FIGURE 2. Toad Lake deer trapping location, September 1957. Photograph by Don Reese.

squaw carpet (*Ceanothus prostratus*) and Sierra plum (*Prunus subcordata*). Large wildfires have resulted in extensive brush fields composed of manzanita (*Arctostaphylos* sp.) and perennial grasses.

The soil is volcanic in origin, with lava tubes, cinder cones and lava flows scattered throughout the area. Due to the porous nature of the soil, water is relatively scarce.

The range is grazed by cattle and sheep through grazing allotments administered by the U.S. Forest Service. Game populations consist of the two sub-species, Columbian black-tailed deer (*Odocoileus hemionus columbianus*), and Rocky Mountain mule deer (*O. h. hemionus*), as well as a hybrid of the two; and black bear (*Ursus americanus*), blue grouse (*Dendragapus fuliginosus*), and mountain quail (*Oreortyx picta*).

TRAPPING DETAILS

The "Improved Deer Snare" (Ashcraft and Reese, 1957), was used to capture the deer. Trapping was carried on intermittently at three sites from July 20 to September 2, 1955, and at two sites from July 26 to August 31, 1956. Figure 1 indicates the trapping sites, location of kill returns and sight records of marked and belled deer. Large concentrations of deer at Toad Lake (Figure 2), Belnap, Harris, and Lava Crack Springs (Figure 3) facilitated trapping. The trapping results are shown in Table 1. The Toad Lake site was re-trapped in 1956 to observe the effects of belling, and the condition of tagging material but no deer were recaptured.

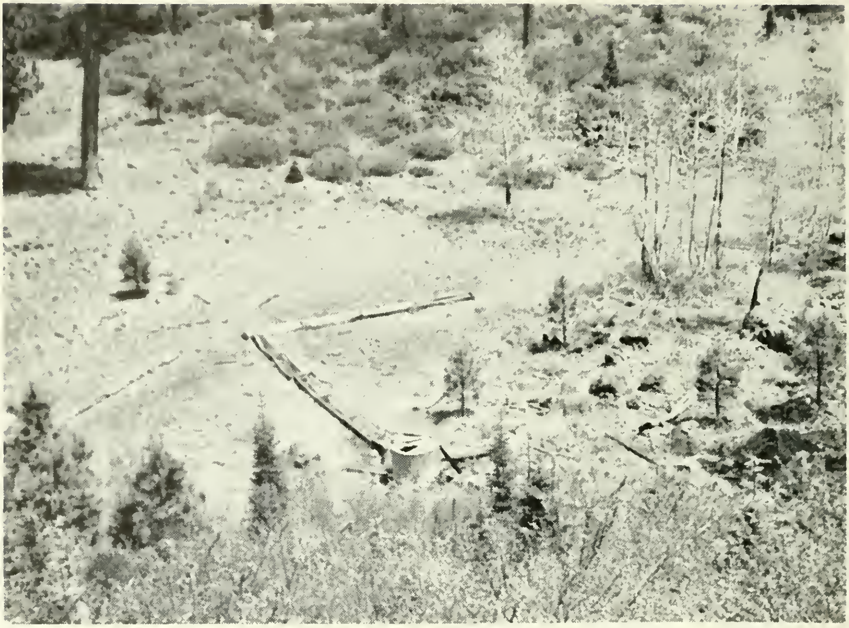

FIGURE 3. Lava Crack Springs deer trapping location, September 1957. *Photo by Bill Aumen.*

MARKING METHODS

In 1955, two types of numbered ear tags were used, the "Salasco" cow tag and the round rivet type tag. The cow tag was superior for it was easier to attach and to observe, and there were none torn out as was the case with two deer that had had the rivet tag. Different designs and colors of a hard vinyl plastic material were used in combination with the rivet ear tag for individual identification.

The use of hard plastic was discontinued because it deteriorated on exposure and was soon lost. Gruell (1958) had a similar experience with marking. Ear cropping combinations were also tried.

A number "8" sheep bell attached to a chain was used on all belled deer. People who observed belled deer indicated that their attention was drawn to the bell and many missed the ear marks. In 1956 all deer

TABLE 1

Trapping Data

Trapping sites	Dates	No. deer trapped	Average no. of traps	No. nights trapped
Toad Lake	7/20 to 8/26/55	46	19	21
	7/26 to 8/31/56	27	13	21
Belnap Springs	8/18 to 8/26/55	9	8	6
Harris Springs	8/29 to 9/2/55	20	12	20
Lava Crack Springs	7/26 to 8/9/56	13	9	9
Total		115		77

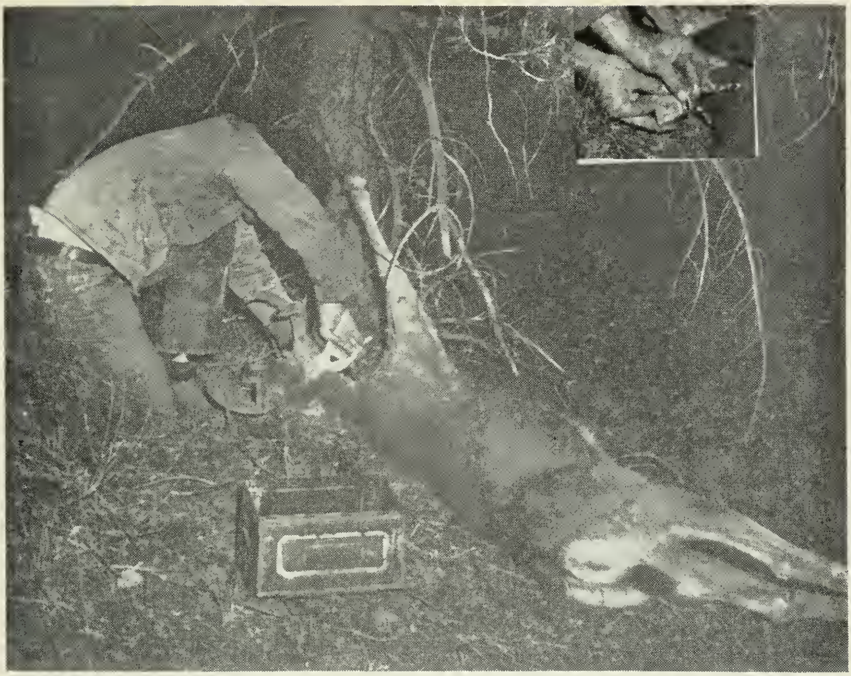

FIGURE 4. Ear tagging and belling a buck at Toad Lake, August 1956. *Photo by Pete Armen.*

were individually marked with flexible vinyl characters of various colors attached to the neck chain.

The chain, bell and neck tags were all attached with hog rings. About 60 pounds pressure was required to separate the hog rings. They were fastened so that the weight of the bell held the neck tags in position on each side of the animal's neck (Figure 4). These proved satisfactory as shown by the following example. Deer No. 22 was trapped in August 1956 and a neck chain with two round yellow plastic discs and a bell was attached. It was killed in September 1958 and the tags were still in good condition.

Belling had no ill effects as indicated by observations of marked animals.

DEER MOVEMENTS

Influence of Water

A drought occurred during 1955. Precipitation from July 1954 through November 1955, totalled 6.35 inches. Use of watering areas by sportsmen began with the archery season. Camp sites were filled with hunters a week before the regular deer season opened. The presence of campers at water sites precipitated early migration to winter ranges in 1955, as no climatic conditions, other than drought, existed which would have induced migration. Movement to the winter ranges customarily takes place in November, and is usually completed by December. Indications of early migration were confirmed when belled

deer were seen at Lairds Well, September 21, at Cold Springs, October 4 and at Pollie Flat, October 6, 1955. All of the above observations were on the Mt. Dome deer winter range.

Lava Crack Spring dried up on August 4, Belnap Springs on August 27, and Toad Lake on August 29, 1955. Movements between watering areas and trapping sites occurred as evidenced by a buck trapped at Toad Lake in August and killed at Lava Crack Springs in September, 1956. Another buck trapped at Lava Crack Springs in August was killed at Toad Lake in September 1956. Approximately three air miles separate these two watering areas. Movements of greater distance to other watering areas were indicated by a buck trapped at Toad Lake in August 1955 and killed near Mayfield Ice Cave on September 27, 1956, a distance of 12 air miles. Also, a buck trapped at Toad Lake in July 1956 was killed near Garner Mountain on September 22, 1956, a distance of 13 air miles.

A comparison of trapping success at Toad Lake during periods prior to and following the desiccation of Lava Crack Springs indicates movements motivated by the need for water. Five deer were caught in four nights of trapping at Toad Lake while water remained at Lava Crack Spring and 13 were captured in four nights of trapping at Toad Lake after Lava Crack Spring dried.

On August 16 and 17 traps were set at Harris Springs. There were very few deer using this area, hence operations were moved to Belnap Springs. Harris Springs was tried again after Belnap and Toad Lake dried. In four nights, 19 deer were taken. Movements to other watering areas at this time were substantiated by observations of belled deer at Slagger Camp, Atkins Springs, Hambone Well and Deter Springs.

Migration Data

Kill returns and sight observations were used to determine the movement of deer from the trapping sites on the summer range. There were 115 deer trapped and marked during the two years of operation. Fifteen of 33 marked deer killed during the hunting seasons, were taken on the winter ranges.

In 1955 one of six tagged, but unbelled legal bucks was reported killed, and in 1956, 21 of the balance of 110 marked deer were reported killed. (Both sexes were legal during the last three days of the 1956 season.) In 1957, six of 33 tagged legal bucks were reported killed, and in 1958, one marked deer was killed. Three were found dead and one was killed on a deer depredation permit on the Mt. Dome winter range. Four were reported killed with no location given. Deer winter range and summer range movements are shown in Figure 1.

Reliable observations of 170 marked and belled deer were made during the study of which 40 were on the summer range (Table 2). Some recorded observations could not avoid repetition of the sightings of deer one or more times.

Observations of marked deer indicated that McCloud Flats deer have a small home range, both in summer and winter, except when affected by adverse weather conditions. Hahn and Taylor (1950) in their studies of a non-migratory deer herd in Texas, found that under adverse conditions a few individuals may range as far as five to seven miles. We have one example of an identified belled deer returning to the same

TABLE 2
Observations of Belled Deer

Winter range area	Miles from trap	Identified	Unidentified
Miller Mountain	32	--	4
Mount Dome	39	12	150
Glass Mountain	28	2	3
Day Bench	12	1	7
McCloud Flats	38	--	1
Lake Britton	27	--	4
Pit River Rims	31	--	1
Total		15	170

area on the summer and winter range for two consecutive years. A belled doe was trapped at Toad Lake, August 4, 1955 and sighted on the Mt. Dome winter range just east of The Three Sisters, February 28, 1956. She was observed at Toad Lake on the summer range on June 13 and on July 24, 1956. By October 26, 1956 she returned to her winter range east of The Three Sisters. This doe was found dead in October, 1957 within one-half mile of previous sightings on the winter range. A belled doe was observed many times at the entrance to the Lava Beds National Monument during the winters of 1955-1956 and 1956-1957, and could be found within a mile of the monument entrance throughout the winter.

A study made earlier (Longhurst, *et al*, 1952) indicated deer on this summer range migrated down to the Day winter range, located approximately 12 miles below the trapping sites. This was substantiated when Deer No. 241, was killed on this winter range, and four belled deer were seen. The author thought that they all moved north to winter on the Mt. Dome winter range, as indicated by the migration trails. Twelve kill and 125 sight records showed that most of the deer moved over the Medicine Lake Divide and wintered on the Mt. Dome range, a distance of approximately 24 air miles, instead of moving 12 miles down to the Day winter range. The Mt. Dome winter range outlined by Longhurst (*op. cit.*) did not extend far enough north. Marked deer in this study demonstrated that an additional 150 square miles is included in the true winter range of this herd (Figure 1).

A theory was that some deer in this study area migrated south and wintered around Shasta Lake. An unidentified belled deer was observed on Potem Creek, Shasta County, during the winter of 1955-56. This would indicate that some deer from this herd move into the Shasta Lake area.

Trapping and tagging studies in California (Leopold, *et al*, 1951) lead us to believe migrations were down drainages. This is true in many cases, as winter ranges are generally located below summer ranges. As the belled and tagged deer reports accumulated, it was evident that a large number of deer were not moving down drainage directly to the nearest winter range. Sight records of 170 belled deer, 5 tagged animals, and 15 killed deer returns proved this. To date belled and tagged deer from a common summer range have been observed on seven different winter ranges only two of which were down drainages.

ACKNOWLEDGMENT

The author wishes to express his appreciation to Don Reese and Clarence Griswold for their assistance in the work on this study. He also wishes to thank the personnel of the Department of Fish and Game, the U.S. Forest Service, the State Division of Forestry and the National Park Service for their cooperation.

SUMMARY

A deer migration study was conducted from 1955 through 1958 on the McCloud Flats in eastern Siskiyou County. Trapping sites were located at Toad Lake, Belnap, Lava Crack and Harris Springs. During 77 nights, 115 deer were caught.

Belling increased the number of observations and neck tags proved superior to other markings for individual identification. Belling had no ill effects as indicated by observations of marked animals.

Summer and winter home ranges were relatively small as observations of marked animals and retraps in the same location were made. The drying of watering places during the drought experienced in 1955 forced deer to seek new sources of water and to extend these home ranges or start on migration.

One hundred and seventy sight records of belled deer, five of tagged animals, and fifteen killed deer returns indicated that deer that summered in the McCloud Flats wintered on seven different winter ranges. Only two of these winter ranges were down drainages from the summer range.

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RESULTS OF THE 1955 TO 1959 PISMO CLAM CENSUSES [1]

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The Department of Fish and Game has censused the Pismo clam populations annually at three locations on Pismo Beach since 1923 and at one Morro Bay location since 1949.

Detailed information regarding censuses prior to 1955 has been presented by Fitch (1952, 1954, 1955). This present paper, in addition to bringing census data up-to-date, includes information on the intertidal distribution of zero-year classes and a history of regulations relating to Pismo clams.

The regular sections, Le Grande, Oceano, Pismo and Morro (Fitch, 1952) were sampled each year from 1955 through 1959 with one exception (Table 1). The Le Grande section was not dug in 1958.

The censuses showed poor clam recruitment at all localities in both 1955 and 1956, and good recruitment in 1957, 1958 and 1959 on the northern end of Pismo Beach. On the other hand, recruitment was quite poor on the southern end of that beach and practically non-existent at Morro Bay. Except for a fair set of young clams in 1952, the last sets of any consequence occurred in 1946 at Pismo Beach and 1944 at Morro Bay.

The number of large-sized clams had declined considerably in all sections by 1959. Good digging now requires working in waist-deep water on the better minus tides. Legal-sized clams (presently $4\frac{1}{2}$ inches greatest diameter) were at least seven years old and most 13 or older in 1959. A reduction of the minimum size limit from 5 to $4\frac{1}{2}$ inches in early 1959 made available to diggers many clams that might not have reached five inches for a number of years, if ever. The lower size limit was adopted to better utilize the clam resource. Census records, dating from 1923 showed there were about five times as many clams at $4\frac{1}{2}$ inches as at five

TABLE 1
Dates of Annual Pismo Clam Censuses
1955-1959

Year	Dates
1955	November 28 to December 1
1956	November 17 to November 20
1957	November 19 to November 22
1958*	November 9 to November 12
1959	November 28 to December 1

* Le Grande section not dug.

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TABLE 2
Number of Clams by Year Class Taken in the Le Grande Section
1955-1959

Year class	Census year 1955	1956	1957	1958	1959
1943+	1	0	0	Not censused	1
1944	1	0	0		1
1945	0	1	0		0
1946	2	7	5		3
1947	2	0	2		1
1948	0	0	0		0
1949	0	0	0		0
1950	0	0	0		0
1951	0	0	0		0
1952	0	0	0		2
1953	0	0	1		0
1954	2	2	2		0
1955	0	0	0		0
1956	--	0	0		0
1957	--	--	13		0
1958	--	--	--		3
1959	--	--	--		23
Total	8	10	23	--	34

inches. Prior to the reduction of the size limit, losses of 4½- to 5-inch clams from clam-forking injuries and failure of clammers to rebury them, were considerable. Since a 4½-inch clam has had at least four and probably five seasons in which to reproduce its own kind, there is little danger of jeopardizing the resource through loss of spawning potential.

LE GRANDE SECTION

This section is located approximately five miles south of Pismo Beach pier in an area that was a clam refuge from 1929 until 1949 (Fitch, 1952). Sets of young clams on this part of Pismo Beach have been poor since 1946. Only 13 clams of the year (zeros) were dug in 1957 and 23 in 1959 (Table 2). The sampling trench was not dug in 1958, but only three clams of the 1958 year class were found there during the 1959 census. Further, in 1959 no two-year-old clams (1957 year class) were dug, indicating an almost total loss of the 1957 year class. Of 34 clams dug in the 1959 census, 26 were one-year-old or younger, the remaining eight were at least seven years old and all were legal sized. Five of these would have been legal at the former five-inch size limit.

OCEANO SECTION

This section lies in an area that was closed to digging from 1949 until 1955. The 1954 census, taken after the area had been closed for five years, yielded 131 clams, 50 of legal size (5 inches at that time). The 1955 census, taken shortly after the area was reopened produced 73 clams, 23 being five or more inches across. Thereafter the number of large clams dwindled rapidly from one census to the next and only one legal clam was sampled in both 1958 and 1959, both from pre-1944 year classes (Table 3).

TABLE 3
Number of Clams by Year Class Taken in the Oceano Section
1955-1959

Year class	Census year				
	1955	1956	1957	1958	1959
1943+	2	3	1	1	1
1944	13	0	0	0	0
1945	13	1	0	0	0
1946	32	10	4	0	0
1947	5	2	0	0	0
1948	1	0	0	0	0
1949	2	0	0	0	0
1950	1	0	0	0	0
1951	0	0	0	0	0
1952	3	7	3	0	0
1953	1	0	0	0	0
1954	0	0	0	0	0
1955	0	0	0	0	0
1956	--	0	0	0	0
1957	--	-	470	45	42
1958	--	--	--	2	27
1959	--	--	--	--	62
Total	73	23	478	48	132

Fortunately, this rather gloomy picture is not entirely without its brighter side. Clam recruitment along this part of the beach was good in 1957, 1958 and 1959. Survival of the 1957 year class was not too good, however. The 1957 census yielded 470 zero clams, but only 45 were taken as one-year-olds in 1958, and 42 as two-year-olds in 1959. The heavy mortality of the 1957 year class probably resulted from the set being late in the year. Most of the zero clams were extremely small (6 to 12 mm) at the time of the census (November, 1957). Zeros usually average more than twice that size at the time of the census, and are probably better able to withstand the rigors of winter than small ones. The 1958 section contained only two zero clams but 27 were dug as one-year-olds in 1959 indicating a better set than expected. The 1959 year class, although not up to some previous ones, was much stronger than any of the 10 between 1946 and 1957.

PISMO SECTION

The Pismo sampling line, located just north of the Pismo Beach pier, lies in an area that has never been closed for digging. As at Oceano, there have been good sets of young clams for the past three years and survival of the 1957 year class was considerably better than at Oceano. In addition, the 1952 year class was relatively stronger in this area than elsewhere and is supplying a fair number of clams to diggers. Of 12 clams older than two years taken in the 1959 census, seven were from the 1952 year class (Table 4). Five of these seven were legal sized and all five of the pre-1952 clams were legal at the present $4\frac{1}{2}$-inch size limit. Only two exceeded five inches. Two of seven 1952 clams dug in 1958 had attained $4\frac{1}{2}$ inches in length and one of 13 dug in 1957. None had reached five inches.

TABLE 4

Number of Clams by Year Class Taken in the Pismo Section 1955-1959

Year class	Census year 1955	1956	1957	1958	1959
1943+	0	0	0	0	1
1944	0	0	1	0	0
1945	0	0	0	0	1
1946	7	7	7	1	0
1947	2	0	0	0	1
1948	0	0	0	0	0
1949	0	0	0	0	0
1950	0	0	0	0	2
1951	2	0	1	0	0
1952	16	35	13	7	7
1953	4	2	9	0	0
1954	8	3	1	3	0
1955	3	2	0	0	0
1956	--	0	0	0	0
1957	--	--	170	31	21
1958			--	6	25
1959					121
Total	42	49	205	51	179

TABLE 5

Number of Clams by Year Class Taken in the Morro Section 1955-1959

Year class	Census year 1955	1956	1957	1958	1959
1943+	3	5	6	0	6
1944	1	0	1	2	1
1945	0	1	1	0	0
1946	1	0	0	0	0
1947	0	0	0	0	0
1948	0	0	1	0	0
1949	0	0	0	0	0
1950	1	0	0	0	0
1951	0	0	0	0	1
1952	2	0	5	0	2
1953	0	0	0	0	0
1954	2	0	1	0	0
1955	3	0	0	0	0
1956		0	0	0	0
1957			0	0	1
1958				0	0
1959					0
Total	13	6	18	2	11

MORRO SECTION

The Morro section is located about one mile north of Morro Rock. There has not been a worthwhile set of young clams in this area since 1944. The 1959 census did not yield zero clams nor did the three previous censuses. Three zero clams were dug in the 1955 sampling line but none has been taken in subsequent censuses. Of 50 clams taken in the last five censuses, 43 were from the 1952 year class or before (Table 5). Of 11 clams censused here in 1959, eight were more than $4\frac{1}{2}$ inches and only one exceeded five inches in diameter.

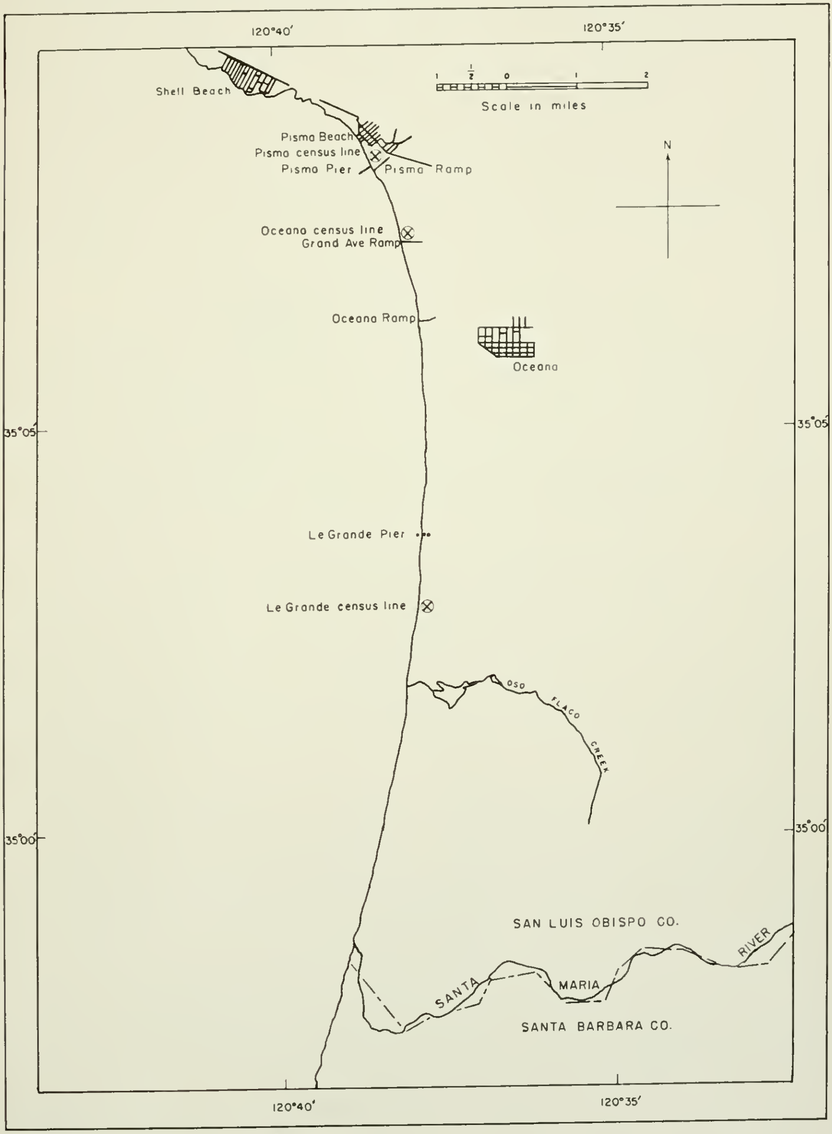

FIGURE 1. Map of the Pismo Beach area showing the locations of census lines and important landmarks.

FIGURE 2. Map of the Morro Bay area showing the location of the census line and important landmarks.

DISCUSSION

With three sizeable incoming year classes on Pismo Beach the future of clamming is somewhat brighter than it has been for a number of years. The lower size limit effected in 1959 made more clams available to diggers and should help to carry them through some inevitable lean years. The 1957 year class now on the beach will not contribute to the fishery much before 1961 and it will be at least 1963 before any sizeable proportion has reached legal size. Until then, successful clamming on Pismo Beach must depend on the 1952 and older year classes. Censuses are yielding fewer old clams each year and there is no doubt that digging will become progressively poorer as older, legal-sized ones are removed by the heavy clamming pressure to which these beaches are constantly subjected.

The already serious situation at Morro Bay doubtless will grow worse and if a good set of young clams is not forthcoming soon it is entirely possible that clamming north of Morro Rock will become unprofitable for a number of years. Even should a good set occur in 1960 it would be at least 1965 or 1966 before many would be legal-sized and much longer before they would provide good digging.

INTERTIDAL DISTRIBUTION OF ZERO CLAMS

Data from 29 censuses of the Pismo section were combined to show the distribution by segment of clams of the year. The Pismo section was chosen for this study because it offered a permanent point of reference from which the segments are laid out, namely, the seawall in front of the town of Pismo Beach. In all other sections the vegetation line (primarily along the seaward edge of relatively permanent sand dunes) is used as a reference point and obviously this can and does vary from year to year.

Commencing at the northwest corner of the seawall, a rope is stretched seaward. The rope is marked off into three-meter segments which are numbered serially from the reference point seaward. The annual census consists of digging a trench six inches wide commencing just below the high tide line and extending seaward as far as feasible. The clams from each three-meter segment are tied in cheesecloth with a label enclosed giving the segment number and the number of clams in that segment. These clams are measured, their age determined and this data recorded by segment.

Since the location of each segment in the Pismo section remains stable it was a simple matter to accumulate the number of zero clams taken in each segment for the period 1924 to 1959. The peak of abundance for zero clams has occurred in segment number 40, between 117 and 120 meters (384-394 feet) seaward from the reference point and approximately 40 meters (130 feet) above the mean low tide line (Figure 3). The first zero clams were encountered in segment 18, increased in number rapidly beginning in segment 28; reached their peak abundance at segment 40; decreased in number rapidly thereafter; and were found in relatively small numbers seaward of segment 63. Thus, it is evident that the census, as now conducted, gives an extermely good measure of the abundance of incoming year classes, in addition to furnishing excellent information on the sizes, age composition and relative abundance of adult populations.

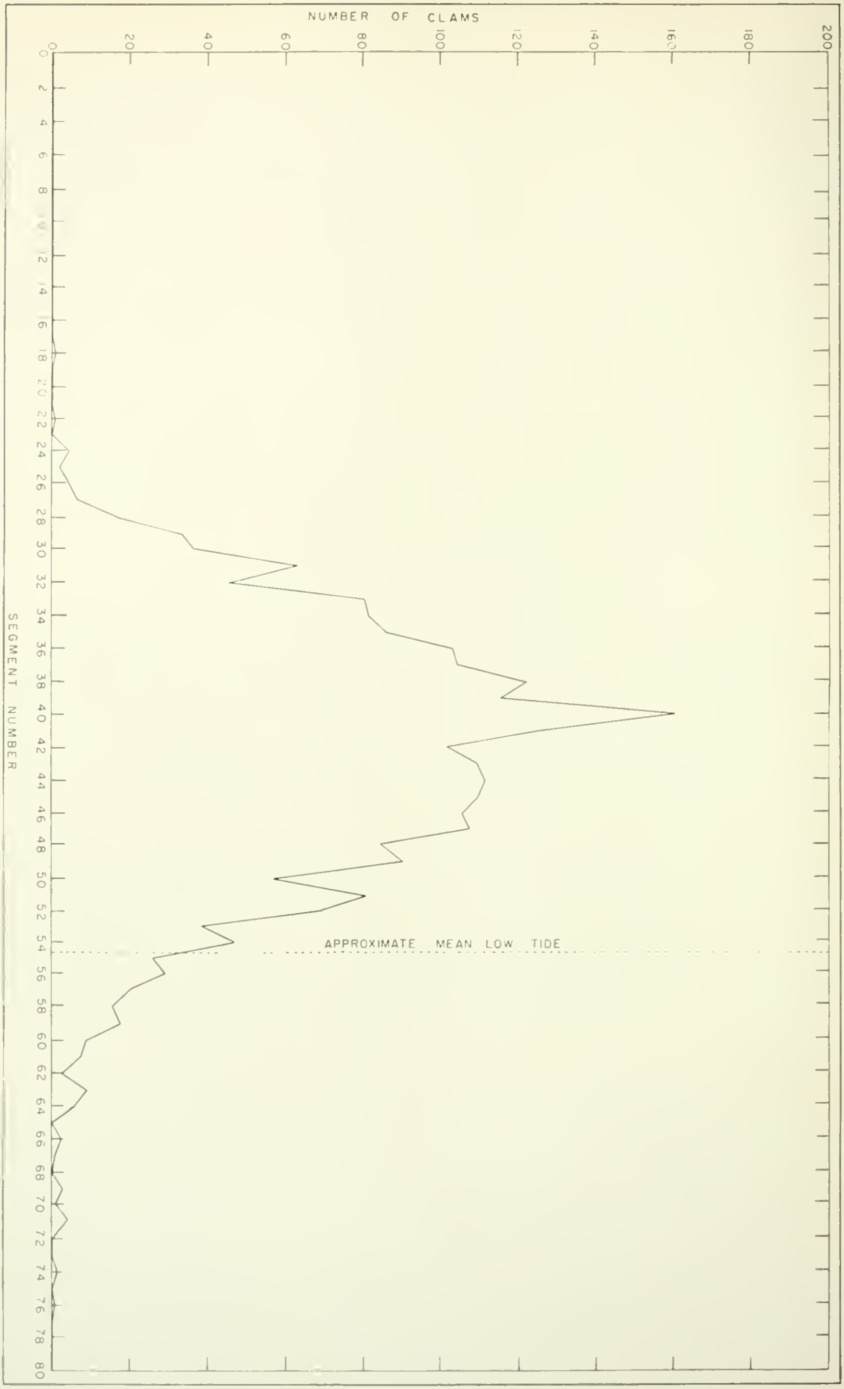

FIGURE 3. Distribution by segment of zero clams in the Pismo Section for the period 1924 to 1959.

TABLE 6

Laws Relating to Pismo Clams

Year	Minimum size limit	Bag limit	Remarks
1911	13 inches circumference (about 4⅞ inches diameter)	200	License required for sale of Pismo clams.
1915	12 inches circumference (about 4½ inches diameter)	50	
1917	4¾ inches diameter	50	Districts 15, 16, 17, roughly Monterey Bay between Pigeon Point and Yankee Point open only between September 1 and April 30 each year. All other districts open the year around.
1921	4¾ inches diameter	36	
1927	5 inches diameter	15	Shipping of clams by common carrier prohibited and no clam out of the shell may be possessed unless being prepared for consumption.
1929	5 inches diameter	15	District 18A, area between Le Grande Pier and Santa Maria River mouth, set up as clam sanctuary, no digging at any time.
1931	5 inches diameter	15	Sportfishing license required to take Pismo clams.
1933	5 inches diameter	15	No digging for clams between ½ hour after sundown and ½ hour before sunrise. No clam digging implements in possession on beach during these hours.
1947	5 inches diameter	15	No Pismo clams taken in California can be sold.
1948	5 inches diameter	10	
1949	5 inches diameter	10	District 18A opened to Pismo clam digging and 8 miles of clam bearing beaches closed in San Luis Obispo County (1.5 miles from Morro Rock north; 2.2 miles between wooden ramps at Oceano and Pismo Beach; 4.6 miles from the San Luis Obispo-Santa Barbara County line to the mouth of Oso Flaco Creek). All undersized clams must be returned to hole from which dug or to deep water.
1950	5 inches diameter	10	The area between Big Cayucos Creek and Old Creek (1.5 miles) closed to digging.
1951	5 inches diameter	10	All undersized clams shall immediately be returned to hole from which dug.
1952	5 inches diameter	10	Open season in Santa Cruz, Monterey, Ventura, Los Angeles, Orange and San Diego Counties from September 1 to April 30. All other counties open all year.
1955	5 inches diameter	10	Opened to Pismo clam digging; 1.5 miles from Morro Rock north; 2.2 miles between wooden ramps at Oceano and Pismo Beach. Closed to Pismo clam digging; 2 miles between the wooden ramp at Oceano and the Old Le Grande Pier pilings; 1 mile at Morro Beach from Hotel Point south.
1959	4½ inches in diameter south of San Luis Obispo-Monterey County Line, 5 inches in diameter north of this boundary.	10	Opened to digging; 2 miles between the wooden ramp at Oceano and the Old Le Grande Pier pilings; one mile at Morro Beach from Hotel Point south. Closed to digging; 2 miles at Morro Beach from Hazard Canyon north to the south end of Morro Bay.

HISTORY OF REGULATIONS

A chronological history of Pismo clam regulations is presented to show the changes that have taken place over a period of years (Table 6). Some of these changes were made to simplify former laws, but most of them were made in an attempt to conserve the Pismo clam resource in California. Prior to 1911, there were no laws in effect on the Pismo clam. In addition to laws effecting Pismo clams taken in California there are laws governing the importation of clams from Mexico. Principal among these is one stating they "may be imported into this State when accompanied by a United States Custom House entry certificate showing a place of origin, and a certificate of clearance from the responsible governmental agency to the effect that such shipment is made in compliance with laws and regulations of the place or country of origin." Such Pismo clams may be canned in California and shipped outside this State.

Since these laws are subject to change at any time one should check current regulations before engaging in clam digging.

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LIFE-HISTORY AND ECOLOGIC NOTES ON THE BLACK CROAKER[1]

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INTRODUCTION

The black croaker, *Cheilotrema saturnum* (Girard) belongs to the Sciaenidae, a fish family containing many important food, game, and bait species in tropical and temperate regions around the world. The croakers are largely confined to shallow waters over sandy and muddy bottoms, chiefly along continental shores; only a few live around coral or rock, about tropical islands or in fresh waters. The family is most abundantly developed along the tropical shores of the eastern Pacific and the Californian species are outliers of that rich fauna.

Eight kinds of croaker are native to California (two others, in recent years, have been successfully introduced into Salton Sea). The largest of the eight, the white seabass, *Cynoscion nobilis* (Ayres), attains a weight of over 70 pounds and is important to commercial and sport fishermen alike. The smallest, the queenfish, *Seriphus politus* Ayres, is utilized almost exclusively for bait. The five other native sciaenids of California are: spotfin croaker, *Roncador stearnsii* (Steindachner); white croaker, *Genyonemus lineatus* (Ayres); yellowfin croaker, *Umbrina roncador* Jordan and Gilbert; California corvina, *Menticirrhus undulatus* (Girard), and shortfin corvina, *Cynoscion parvipinnis* (Ayres). A ninth species, *Sciaena thompsoni* Hubbs, was once recognized, but recently has been shown to have been based on a young yellowfin croaker and thus is not valid (Carl L. Hubbs, personal communication).

Except for the black croaker and the shortfin corvina, all native Californian sciaenids are commonly captured and are familiar to most fishermen in southern California, where, within the state, several of the species are largely confined. The lack of familiarity with the short-

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Editorial Note.—This report, based on a manuscript prepared by the author prior to his death, has been revised and brought up-to-date by Howard M. Feder, Hartnell College, Salinas, California. Carl L. Hubbs, under whom Conrad Limbaugh worked as a graduate student, and John E. Fitch assisted in the preparation of the final draft.

Conrad Limbaugh, chief diving officer at Scripps Institution of Oceanography and one of the world's foremost underwater naturalists, had been working on numerous and diverse research projects before he met an untimely death in a diving accident in the Mediterranean on March 20, 1960. Many of his projects, including this paper, were left unfinished. However, because of the extensive field notes and photographic records he maintained, it is anticipated that the results of most of these studies can be assembled and eventually published so the vast wealth of his accumulated knowledge will not be lost.

fin corvina is readily explained, because only on rare occasions and in small numbers, during the present century, has it visited our shores from the south. The black croaker, however, as the present study shows, is relatively abundant in southern California; it has kept out of the fishing public's eye by reason of its retiring habits.

During recent years, with the advent and development of SCUBA diving which has increasingly been applied to scientific research under water, the secretive habits of the black croaker have been revealed, and its life history has been elucidated. Bits of information have been pieced together until now a relatively connected account of its life ways can be formulated. This knowledge has accrued primarily as a result of countless hours of underwater observation at all seasons, over a period of more than 12 years. It has been supplemented by observations, over a two-year period, of young individuals in aquaria at the Scripps Institution of Oceanography (particularly of one very young individual whose daily progress and color transformation was closely followed).

Most of the diving was done at Point Dume, Santa Catalina Island, Newport Beach, Laguna Beach and La Jolla, in California, and at the Coronado Islands, Ensenada and Playa María Bay, Baja California. During the course of the investigation, specimens were collected at Newport Beach, Corona Del Mar, La Jolla and Ensenada.

Without such knowledge as has been acquired, intelligent management of the resource, should it become desirable or necessary, would not be possible.

DISTRIBUTION

The distribution of the black croaker has been variously stated by different authors, as follows:

"Santa Barbara southward" (Jordan and Gilbert, 1881b).

"Pacific Coast, north to Point Concepcion" (Jordan and Gilbert, 1883).

"Coast of Southern California, north to Santa Barbara" (Jordan and Eigenmann, 1889).

"Coast of Southern California, from Santa Barbara to Cerros Island" (Jordan and Evermann, 1898).

"Santa Barbara south to the Gulf of California" (Starks and Morris, 1907).

". . . has not been reported north of Santa Barbara. Its range extends southward along the coast of Lower California" (Starks, 1919).

"Santa Barbara to Cerros Island" (Ulrey and Greeley, 1928).

"Point Conception to Cerros Island on the coast of Lower California" (Walford, 1931).

"Gulf of California to Santa Barbara" (Barnhart, 1936).

"Coast of California and west coast of Mexico, from Point Conception southward into the Gulf of California" (Skogsberg, 1939).

"Point Conception south along the Mexican coast and into the Gulf of California" (Roedel, 1948 and 1953).

"Santa Barbara to Cape San Lucas, and into Gulf of California" (Cannon, 1953).

"Costa de California desde Punta Concepcion hasta el Golfo de California" (Berdegué A., 1956).

Specific locality records are given as follows:

"San Diego", or "San Diego Bay" (Girard, 1858; Günther, 1860; Steindachner, 1879; Smith, 1883; Jordan and Gilbert, 1880, 1881a; Eigenmann, 1892; Eigenmann and Eigenmann, 1892; Starks and Morris, 1907).

"San Pedro" (Jordan and Gilbert, 1881b; Eigenmann and Eigenmann, 1892; Craig, 1926, 1928).

"Santa Barbara" (Jordan and Gilbert, 1881b; Eigenmann and Eigenmann, 1892).

"Gulf of California" (Albatross Station 3026 . . .) (Starks and Morris, 1907).

"Newport" and "Laguna" (Metz, 1912).

"Venice" (Ulrey and Greeley, 1928).

Specimens in the Scripps Institution of Oceanography collection were taken at and near La Jolla, Mission Bay and San Diego Bay, in California, and in Todos Santos, Playa María and Turtle bays, and at Lagoon Head, in Baja California. John E. Fitch (personal communication) indicates there are no reliable reports of black croakers south of Santa María Bay, Baja California.

The range of the species, according to present indications, extends from the Santa Barbara Channel in California (near Pt. Conception) to Santa María Bay in southwestern Baja California. The inclusion of the Gulf of California in the range has rested on two specimens collected by the *ALBATROSS* on March 25, 1889, at Lat. 31° 22′ 00″ N., Long. 114° 07′ 45″ W., near the head of the Gulf. A comparison of these with the two cotypes of *Amblodon saturnus* Girard (1858) disclosed differences that seem to indicate the form occurring in the upper part of the Gulf is either specifically or subspecifically distinct. The only other member of the genus *Cheilotrema* is a very similar form in Peru, namely *Cheilotrema fasciata* Tschudi (1845), the type species of the genus (Carl L. Hubbs, personal communication).

The California species has been referred successively to the genera *Amblodon, Rhinoscion, Corvina, Sciaena* and finally *Cheilotrema*, where it may rest pending the much needed revision of the eastern Pacific sciaenids (Carl L. Hubbs, personal communication).

IMPORTANCE AND ABUNDANCE

Earlier authors rated the black croaker a food fish of some importance (Jordan and Eigenmann, 1886; Jordan and Evermann, 1898; Walford, 1931; Hiyama, 1937; and others). It was reported abundant in San Diego Bay by Eigenmann (1892), and the "Chinese croaker," as it was called, was commonly caught there in the first decade of this century (Carl L. Hubbs, personal communication). Metz (1912) stated that it was common at Newport and Laguna.

Although later authors (Skogsberg, 1939; Roedel, 1948, 1953; and others) have regarded it as rather rare, diving observations have revealed it is fairly common and black croakers do occur rather frequently in the spear fisherman's catch. Very likely, however, the species was more abundant in former years. Pollution may have played an important role in limiting their numbers, especially in San Diego Bay and in the metropolitan district about Los Angeles. Part of the decrease, however, may be attributable to a change in fishing gear: the large beach seines formerly used to supply the fresh fish market probably were much more effective than the gear currently used for catching them.

HABITAT

The habitat of the black croaker has been reported as the open coast, bays, sloughs and fairly deep water (Skogsberg, 1939; Roedel, 1948, 1953). In the present study, adults were observed only along open rocky coasts, although a few juveniles were seen near rocks in the entrance to Newport Bay. The adults generally have been associated with rocks, and most were in fair-sized rock caves or dark crevices, but in murky water several schools were noted 8 to 10 feet off the bottom in patches of ribbon kelp, *Egregia laevigata* Setchell. The aggregations in the caves were often so dense that a single thrust with a spear would impale one or two small adults. Occasionally during the summer some adults, displaying the juvenile striped color pattern described below, were observed over sand patches among the shallow reefs. (It should be kept in mind, however, that diving was heavily concentrated in rocky areas).

Although adult black croakers usually live in water 10 to 50 feet deep, they have been observed on rare occasions as deep as 150 feet and as shallow as four. Their center of abundance is at approximately 21 feet. Their rarity in deeper waters, in the areas of observation, may have been due to lack of suitable rock crevices or caves there.

In more turbid waters, as in the coastal bays where they have been seined and trawled in considerable numbers, black croakers are apparently much less restricted to rocky retreats (Carl L. Hubbs, personal communication).

The young, to a standard length of about 88 mm. (3.5 inches) are concentrated at a depth of about 8 to 10 feet, and range from 4 to 18.

APPEARANCE AND HABITS OF THE ADULTS

The adults are easily approached in caves and tunnels 10 to 50 feet below the surface, where their deep brown or black color renders them almost invisible to the human eye. Outside the caves and tunnels they are in almost constant motion, and when approached promptly seek shelter among the rocks.

Their ability to change color has given rise to several unauthorized common names, such as blue fish (Craig, 1928), black perch (Walford, 1931; Craig, 1926), black bass and blue bass (Craig, 1926; Walford, 1931; Roedel, 1948, 1953), striped croaker, and blue croaker. A number of distinct color patterns have been observed in adults. The coloration developed in the caves is dark brown, at times with a faint dark band across the anterior back. This band is said to fade with age (Starks, 1919), and to become more distinct at night (Barnhart, 1936). Except for cream-colored spots, the night pattern (Figure 1) is essentially the same as that displayed in caves during daylight. A light tan color, without the band, may be displayed in clear, open water, whereas a striped pattern is assumed over sand patches, especially by juveniles.

The striped pattern provides good protection on the sand. The longitudinal stripes against a background of ripple marks render them almost invisible to the human eye at a distance of 15 feet. The assumption of the striped pattern by the adult may also be related to breeding. Any sand-colored or light-colored fish is difficult to see against

FIGURE 1. A live adult black croaker, *Cheilotrema saturnum*, exhibiting the nocturnal color pattern. *Photograph by Conrad Limbaugh.*

a sand background, but the stripes blend so well with the parallel sand-level marks at the bases of rocks. to which the fish retreat when frightened, as to increase markedly the concealing effect. Striped individuals seldom or never retreat into caves or rock crevices, whereas dark or tan-colored ones always do. A striped fish turns dark when speared. Black croakers when brought to the surface may appear bluish or olive. On the upper parts of the fish, the scale bases have a coppery luster becoming whiter on the lower parts.

FOOD

Black croakers have been reported to eat small crabs and shrimps (Skogsberg, 1939). The present study indicates they feed exclusively on crustaceans, and mainly on rock-dwelling crabs such as the lumpy crab, *Paraxanthias taylori* Stimpson and young moss-covered crabs, *Loxorhynchus crispatus* Stimpson. The lumpy crab seems to be favored. Red-and-white shrimp, *Hippolysmata californica* Stimpson, and various amphipods, are also consumed. In general, the black croaker is nocturnal in its feeding and other behavior.

SPAWNING

Spawning takes place in the late spring and early summer (Skogsberg, 1939). Plankton tows over the breeding grounds of San Diego Bay from May through August (Eigenmann, 1892) and at La Jolla in the summer have yielded collections of their eggs. A striped female speared in August had ripe ovaries. Juveniles have been taken only in August, September and October.

Clusters of striped adult black croakers mixed with aggregations of striped and barred adults of the California sargo, *Anisotremus davidsoni* (Steindachner) have been observed early in July, in shallow water over sand patches near rocks. The almost constant motion of these fish, repeatedly covering the same area, seemed to represent breeding behavior.

Eigenmann (1892) reported that black croakers emit croaking sounds during the breeding season. Croaking or drumming noises apparently produced by black croakers have been detected at the entrance to Newport Bay, but were not correlated with spawning behavior.

Eigenmann further indicated that males entered San Diego Bay in January and February, and that ripe males were taken there in March

FIGURE 2. A black croaker 14 mm. in standard length collected September 6, 1950, the smallest specimen obtained during the investigation. *Photograph by Conrad Limbaugh.*

and ripe females in April and May. Possibly due to the more rapid increase of temperatures in the bays, breeding occurs earlier there than along the open coast.

The tiny, colorless eggs, 0.78 mm. in diameter, resemble those of the diamond turbot, *Hypsopsetta guttulata* (Girard). They are pelagic and drift with the currents until they hatch. They are reported to hatch within 18 to 48 hours (Eigenmann, 1892).

CHANGES IN COLORATION AND GROWTH OF THE YOUNG

The smallest black croaker taken during this study was slightly shorter than 14 mm. in standard length when photographed six days after capture (Figure 2). It was caught on September 6 at a depth of about 10 feet near a rocky reef, within 18 inches above the sand bottom. It was swimming at the rear of a school of striped black croaker, California sargo and California salema, *Xenistius californiensis* (Steindachner), juveniles. Some adult black croakers also were included.

This young fish, which was estimated to be from four to six weeks old, differed markedly from the other juveniles and the adult black croakers in the school. The lips, top of the head, opercle and trunk back to the soft dorsal were black, except for a light-tan blotch on top of the head in front of the eye and another blotch on the nape. The underside of the head and body in advance of the pelvic fins was translucent tan. The posterior half of the fish was transparent, except for some prominent black markings. An intensely black median

stripe, as wide as the eye, extended from its origin, slightly before the vertical through the anus, backward to the midline of the caudal peduncle. Following a constriction on the peduncle, the band broadened into an inky-black rather oblong blotch. This blotch was almost completely separated by a vertical light streak from a narrow blackish crescent at the extreme base of the caudal rays. Other black marks on the body comprised two linear spots at the base of the dorsal soft-rays, and a similar spot at the base of the anal rays. This latter was

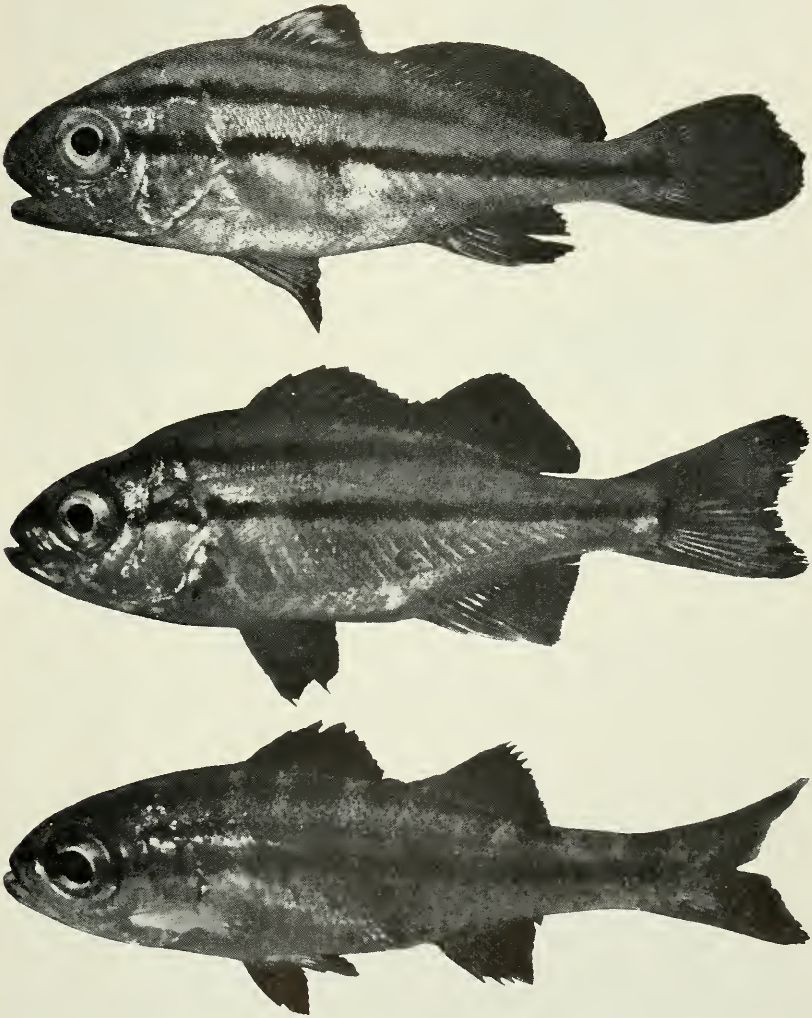

FIGURE 3. (Top.) The 14 mm. juvenile (Figure 2) after six weeks growth in an aquarium; standard length now 25 mm. The downward-curved anterior pelvic ray is typical for juvenile black croakers and apparently is of some sensory significance. (Center.) Juvenile California sargo, *Anisotremus davidsoni,* collected October 17, 1950 and photographed October 24, 1950. (Bottom.) Juvenile California salema, *Xenistius californiensis,* collected September 6, 1950; photographed October 24, 1950. Note the striking similarities in the juvenile color patterns of the three species, all of which school together. *Photographs by Conrad Limbaugh.*

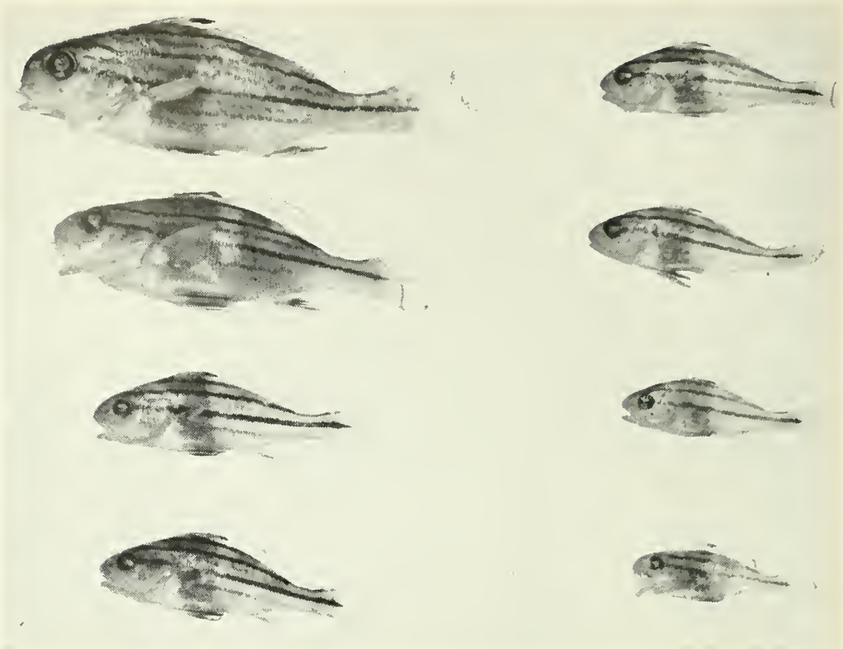

FIGURE 4. A series of juvenile black croakers, collected August 30, 1950, exhibiting the colorational changes that occur with increasing size (24 to 58 mm. in standard length). *Photograph by Conrad Limbaugh.*

in line with about four not completely separated spots on the ventral edge of the caudal peduncle.

The pelvics, pectorals and tip of the spinous dorsal were black. The anal fin carried a few dusky specks anteriorly, chiefly along its base. The lower two-thirds of the spinous dorsal was whitish, somewhat speckled, darkening to gray at the base. The soft dorsal and caudal were indistinctly speckled outward. The pupil was black, the iris gray. The black lining of the body cavity showed through the flesh.

It was maintained alive in an aerated aquarium supplied with running sea water. For the first few weeks it was fed live brine shrimp, which it ate regularly. As it grew, this diet was supplemented by mussel (*Mytilus* sp.), fish and chopped liver. In six weeks it grew to a length of 25 mm. and had assumed the juvenile color pattern. It now swam closer to the bottom of the aquarium.

At this 25 mm. size (Figure 3, top) it bore three black stripes, each much narrower than the eye. One, originated on the snout, extended through the eye, and continued, along the midline of the sides, to the base of the caudal fin. A slightly narrower stripe began above the eye and extended to the top of the caudal peduncle. The third and uppermost stripe roughly paralleled the dorsal contour from a point just above and behind the eye to the front of the soft dorsal. The background color was silvery-gray. The fins were colored much as at the

14 mm. stage, except for the slight yellowish color in the caudal and a clearing of the pectorals; the anterior pelvic rays had become silvery and elongated, with a downward curve at the tip. Presumably this modification of the pelvic fin has some sensory significance, for at this size black croakers begin to swim close to the sand.

Another pattern (Figure 4), superimposed when fish at this size become sick, frightened or preserved, is normally exhibited at night. The nocturnal coloration is a modification of the pattern characterizing the 14-mm. stage day and night. The principal feature is a vertical brown bar four-fifths as wide as the head at the base of the first dorsal fin, narrowing downward to half this width at the abdomen.

By the time they reach the length of 32 mm., black croakers have developed a fourth lengthwise stripe, below the other three. It extends from the pectoral fin to the lower edge of the caudal peduncle, where it continues to the tail fin.

At 38 mm. the nocturnal pattern is modified by two additional bars, which at their origin along the base of the soft dorsal are half as wide as the head is long. These bars fade out near the midline of the body.

By the time the young attain a length of 50 mm. the two posterior bars have become fused and cover the entire posterior half of the fish, with the exception of a whitish spot at the base of the soft dorsal fin. The fish now appears to be dark-brown, with a light band below the front of the soft dorsal. The lengthwise stripes are still readily discernible through this color pattern, and somewhat interrupted dusky stripes have become interpolated between the main blacker stripes.

When they attain a standard length of about 120 mm. (nearly five inches), black croakers become much darker, but retain the light bar at night. This seems to be the same light bar that is exhibited by adults at night (Figure 1).

The juvenile color pattern is so different from that of the adults it led to the erection of a nominal species, *Corvina jacobi* (Steindachner, 1879). In a parallel situation, Hubbs and Walker (1951) showed that the strongly striped young of *Elattarchus archidium* (Jordan and Gilbert), which superficially resemble young black croakers, had been described as *Odontoscion australis* Meek and Hildebrand.

HABITS OF THE YOUNG

Under natural conditions juvenile black croakers 14 to 50 mm. in standard length school together with the young California sargo and California salema (Figure 3, center and bottom). All three have remarkably similar striped color patterns (Steindachner, 1879, commented on such parallel color patterns).

Once formed, such a school or aggregation is maintained near the base of a rock, over sand bottom, in water 4 to 18 feet deep, along the open coast just beyond the surf. The rocks obviously afford protection from the surge. Within the somewhat lenticular-shaped school the individuals are 6 to 10 inches apart, and all face directly into the constantly reversing surge. Those schools observed did not shift their position more than 10 feet during an entire season. Within the school, however, the species, size and number of fish fluctuated from day to day.

As they become larger, black croakers break away from the main school and retire to caves and crevices. Half-grown individuals 88 to 150 mm. long tend to lead a solitary existence. Single fish about 150 mm. (six inches) long are not uncommon in crevices. They do not maintain schools in particular recesses, but seem to wander freely among crevices or caves.

SIZE AND AGE

According to Skogsberg (1939) black croakers mature at a standard length of about 22 cm. (8.7 inches). Observations made somewhat incidentally throughout the year suggest that at this size they are two or three years old and are schooling with larger adults, usually in caves and dark crevices.

On mature fish, most of the scales examined had been regenerated, but a few readable ones almost always could be found. Scales from a female 10.5 inches long had four distinct annuli. The ear bones (otoliths) of a female 11.25 inches in total length showed five winter rings and those from a fish 14.0 inches in total length (sex not determined) had 20 (John E. Fitch, personal communication).

Black croakers were reported by Jordan and Gilbert (1881), perhaps not as a result of definite measurements, to attain the length of 18 inches. Lengths to 15 inches have been indicated by other writers (Jordan and Evermann, 1898; Starks, 1919; Walford, 1931; Barnhart, 1936; Roedel, 1948, 1953). The largest adults observed in the course of diving were an estimated 14 inches long, but the largest ones collected measured only slightly more than 11. The California State Fisheries Laboratory has a record of a female 14.25 inches in total length (11.5 inches standard), weighing 1 pound, 9 ounces, that was taken off Seal Beach on March 10, 1959 (John E. Fitch, personal communication).

METHODS OF CAPTURE

Black croakers have been taken with gill nets, round-haul nets, hook and line, and beach seines (Walford, 1931); and by using lampara nets (Skogsberg, 1939) and set lines (Roedel, 1948, 1953). Some have been killed by explosives (Fitch and Young, 1948), and others have been taken by spear fishermen. During this investigation specimens were collected by angling, by diving with spears and small hand nets, and by using rotenone.

IMPORTANCE

The black croaker is probably more abundant than the highly-prized California corbina, but is seldom taken by either commercial fishermen or anglers. It is not as large as some of the other California croakers, but is quite palatable and potentially valuable as a food fish.

Since 1933 it has been illegal to sell black croakers (Roedel, 1948). They are taken only incidentally by commercial fishermen. As a result of their present scarcity in bays, their retiring habits on the open coast and their comparatively small size, it is doubtful that a successful commercial fishery could be established, even if their sale were legalized.

SUMMARY

Many features in the life history and ecology of the black croaker, *Cheilotrema saturnum* (one of the eight native sciaenids of California) have been elucidated through underwater observations, rearing in aquaria and literature review.

The species ranges from the Santa Barbara Channel (about Pt. Conception) in California to Santa Maria Bay, Baja California. Related forms occur in the Gulf of California and off Peru. Adults have been reported from bays and sloughs as well as the open coast, but were observed only while diving along rocky coasts, in water 4 to 150 feet deep, with their abundance centering at about 21 feet. They are generally very retiring in habits, chiefly frequenting caves and crevices. Juveniles, smaller than 88 mm. (3.5 inches) in standard length, were noted in depths of 4 to 18 feet with a concentration at about 9.

Adult black croakers undergo changes in coloration of apparent adaptational significance. The nocturnal pattern is distinct from the diurnal. The coloration changes remarkably between the attainment of standard lengths of 14 to 120 mm. The juveniles strikingly resemble the young of the California sargo, *Anisotremus davidsoni*, and the California salema, *Xenistius californiensis,* and the young of these three species school together.

Black croakers appear to feed exclusively on crustaceans. They mature at a standard length of about 22 cm. (9 inches) and spawn in late spring and early summer. A total length of 18 inches has been attributed to the species but most authors give the maximum size as 15 inches. The largest ones observed in diving were estimated to be 14 inches long. A 14.25-inch female checked by the Department of Fish and Game weighed slightly more than a pound and a half.

Published statements indicate black croakers were formerly more abundant, especially in non-polluted bays. They have been regarded as now rare, but diving observations disclosed considerable abundance. The black croaker is a palatable food fish, but the development of any considerable fishery for it seems unlikely.

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DESCRIPTIONS OF POSTLARVAL AND JUVENILE BONITO FROM THE EASTERN PACIFIC OCEAN[1]

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INTRODUCTION

The Pacific bonito, *Sarda chiliensis* (Cuvier)[2], is a pelagic, temperate-water, schooling species having a discontinuous distribution in the eastern Pacific Ocean. In the northern hemisphere, they range from Banderas Bay, Mexico to British Columbia, the center of abundance oscillating seasonally between central and northern Baja California and southern California. In the southern hemisphere they have been reported from Panama to central Chile. According to Vildoso (1955), 70 percent of the Peruvian catch is taken in the Chimbote-Pisco (Lat. 09° to 14°S.) area while in Chilean waters they are most abundant between Arica and Antofagasta (Lat. 19.5° to 23.5°S.).

The magnitude of the bonito fisheries off the west coasts of the Americas is small compared to the harvest of herrings, cods and tunas in other parts of the world. They do, however, contribute significantly to local economies. Peru's commercial bonito fishery, for example, yields a product of value for domestic use as well as for export (Vildoso, 1955). In California bonito are exploited by both commercial and sport fishermen. Although the commercial product has had but limited acceptance throughout the years, a growing army of recreational fishermen since World War II has opportunely cropped them in increasing numbers.

Bonito catch statistics are meager and undoubtedly represent minimal values (Table 1). They do present, however, a rough measure of exploitation which perhaps is limited more by economics than by natural causes. The California landings include sport-caught bonito which had been reported by the party boat operators in numbers of fish. For comparison with the other data a factor of four pounds per fish was used to convert numbers to pounds.

A second species, *Sarda velox,* is found from central Baja California to Peru, including the Galapagos Islands. It is of little commercial importance but when captured it may enter catch statistics as *Sarda chiliensis.*

The steadily increasing commercial importance of the bonitos plus their close alliance to the valuable tuna fisheries make it desirable to learn as much of their biology as possible. Particularly lacking has been information on the early life history. The fertilized egg and larvae

[1] Submitted for publication September 1960.
[2] Hildebrand (1946) believed *Sarda lineolata* (Girard) to be synonymous with *S. chiliensis* (Cuvier). Godsil (1955), in a more detailed study of *Sarda,* arrived at the same conclusion.

TABLE 1

Bonito Landings in the Eastern Pacific Ocean in Thousands of Metric Tons[1,2]

Year	Northern Hemisphere			Southern Hemisphere			Grand Total
	California[3]	Mexico	Total	Peru	Chile	Total	
1949	0.8	0.7	1.5	--	--	--	1.5
1950	0.3	1.0	1.3	31.8	--	31.8	33.1
1951	0.4	0.1	0.5	51.2	-	51.2	51.7
1952	1.0	1.1	2.1	50.3	4.9	55.2	57.3
1953	1.4	0.6	2.0	44.4	2.0	46.4	48.4
1954	1.2		1.2	52.8	4.4	57.2	58.4
1955	0.1	--	0.1	71.8	8.0	79.8	79.9
1956	0.2	-	0.2	83.8	4.4	87.8	88.0
1957	0.6		0.6	58.6	2.1	60.7	61.3
Total	6.0	3.5	9.5	444.7	25.8	470.1	479.6
Average	0.66	0.70	1.06	55.58	4.30	58.75	53.28

[1] Sources: Berdegue, (1956); California Department of Fish and Game Catch Statistics; F A O Yearbooks of Fishery Statistics; and Vildoso, (1955).
[2] One metric ton = 1.10 U. S. short tons.
[3] Includes sport-caught fish.

shortly after hatching were reported on by Barnhart (1927) and by Orton (1953a and 1953b).

METHODS

During the course of collecting biological material and other scientific data from commercial fishing vessels and research ships operating in the eastern Pacific Ocean, staff members of the South Pacific Fishery Investigations of the U.S. Bureau of Commercial Fisheries, Scripps Institution of Oceanography and the California Department of Fish and Game have captured a variety of larval and juvenile fish including *Sarda chiliensis*. Details on the capture of the young bonito were kindly placed at the author's disposal by these organizations (Table 2). The offshore localities where these larvae and juveniles were collected range from southern California to Chile with a majority from the waters off Cape San Lucas, Baja California (Figure 1).

Most of the postlarval fish were dipnetted at night when they were attracted to and swam under an incandescent light suspended above the surface of the water. Although light intensity was not measured, it varied from cruise to cruise depending upon the bulbs available (ranging from 150 to 1,500 watts) and the actual output of the various shipboard generators. Almost all of the juvenile bonito were taken incidentally in bait nets by tuna fishermen.

All observations were made on specimens originally preserved in formalin. The nomenclature of the various body parts follow Matsumoto (1958). Measurements are straight-line distances obtained with dividers. Fork length, the distance from tip of the snout to the tip of the shortest median caudal ray, has been used to describe the lengths of the fish in accordance with current common practice for tunas. Head length was measured from the tip of the snout to the posteriormost edge

FIGURE 1. General localities where 35 postlarval and juvenile bonito were captured in the eastern Pacific Ocean between 1947 and 1960.

of the subopercular bone. The gill raker count includes all visible protuberances. The basis for separating the abdominal and caudal vertebrae is patterned after Hubbs and Lagler (1947).

The terminology applied to the various life stages, namely postlarva and juvenile, follows Hubbs (1943).

IDENTIFICATION AND DESCRIPTIONS OF POSTLARVAE AND JUVENILES

In general external appearance the 32 specimens examined resembled numerous published descriptions and illustrations of scombroid fishes (Kishinouye, 1919; Ehrenbaum, 1924; Wade, 1950; and Matsumoto, 1958). They most closely resembled postlarval and juvenile *Sarda sarda*

TABLE 2

Catch Data for 35 Postlarval and Juvenile **Sarda chiliensis** from the Eastern Pacific Ocean

Date	General locality	Latitude	Longitude	Method of capture	Size range fork length in mm.	No. of specimens	Tempera-ture	Reference or collector
NORTHERN HEMISPHERE								
May 17-18, 1947	Off La Jolla, California, U. S. A.	----	----	night light dip net	----	1	----	Hubbs[1]
Aug. 5, 1951	100 miles N. W. of Cape San Lazaro, Baja Calif., Mexico.	25°35′N.	113°56′W.	night light dip net	42	1	----	Fish & Wildlife Service[2]
July 15, 1953	S. of Cape San Lazaro, Baja Calif., Mexico	23°47′N.	112°25′W.	night light dip net	25-41	5		Leo Pinkas[3]
July 18, 1953	S. W. of Cape San Lazaro, Baja Calif., Mexico	23°16′N.	112°45′W.	night light dip net	19-41	8		Leo Pinkas[3]
April 11, 1955	S. of Cape San Lucas, Baja Calif., Mexico	22°52.8′N.	109°53.7′W.	night light dip net	16.7	1	19.8°C	John E. Fitch[3]
July 11, 1956	S. W. of Cape San Lucas, Baja Calif., Mexico	23°35′N.	112°11′W.	night light dip net	33.0-33.5	2	24.8°C	Tom Jow[3]
July 12, 1956	S. W. of Cape San Lucas, Baja Calif., Mexico	22°20′N.	112°27′W.	night light dip net	24-48	8	24.2°C	Tom Jow[3]
July 17, 1956	S. W. of Cape San Lucas, Baja Calif., Mexico	22°17′N.	112°14′W.	night light dip net	54.5	1	24.6°C	Tom Jow[3]
SOUTHERN HEMISPHERE								
Dec. 15, 1957	Off Ilo, Peru	17°38′S.	71°18′W.	bait net	200.9	1	16.6°C	John Seapin[3]
Dec. 13, 1957	Off Ilo, Peru	17°38′S.	71°23′W.	bait net	121	1	18.9°C	John Seapin[3]
Dec. 21, 1957	S. of Santa, Peru	09°31′S.	78°26′W.	bait net	38.0-51.0	5	20.5°C	John Seapin[3]
Jan. 1, 1958	Off Ilo, Peru	17°47′S.	71°30′W.	bait net	86.8	1	20.5°C	John Seapin[3]
TOTALS	----				16.7-200.9	35		

[1] Field-book data of Carl L. Hubbs, Scripps Institution of Oceanography, La Jolla, California.
[2] In the collection of the South Pacific Fishery Investigation, United States Bureau of Commercial Fisheries, La Jolla, Calif.
[3] In the collection of the California Department of Fish and Game, Terminal Island, California.

TABLE 3
Selected Meristic Counts on 32 Postlarval and Juvenile **Sarda chiliensis**, 16.7 to 200.9 mm.

Fork length mm.	Dorsal fins			Anal		Anterior gill rakers				Posterior rakers	Lower jaw teeth	
	1st	2nd	Finlets	Fin	Finlets	Upper limb	Angle	Lower limb	Total		Right	Left
16.7	20	12	8	12	7	2	1	11	14	not evident	15	13
19.0	19	14	8	13	7	2	1	10	13	"	14	14
23.4	19	14	8	15	7	2	1	9	12	"	16	16
24.0	19	14	8	14	7	2	1	14	17	"	15	16
24.0	19	15	8	13	7	3	1	14	18	"	16	14
25.0	19	14	8	14	7	2	1	13	16	"	19	17
29.0	20	14	8	14	7	4	1	15	20	"	14	15
30.5	19	14	8	14	7	4	1	15	20	"	15	16
31.0[1]	20	14	8	11	7	3	1	14	18	"	20	22
32.0[1]	20	14	8	14	6	4	1	15	20	"	21	25
32.2	20	14	8	13	7	4	1	16	21	"	17	16
33.0	19	13	8	11	7	4	1	16	21	"	19	19
33.5	20	14	7	11	7	3	1	18	22	"	15	16
33.5	19	14	8	13	7	4	1	14	19	"	16	17
36.0	19	15	8	11	7	4	1	15	20	"	18	16
38.0	19	15	8	14	7	4	1	16	21	present	18	17
38.0	19	14	8	13	7	5	1	16	22	"	16	17
40.0	18	14	8	14	7	6	1	17	24	"	14	15
41.0	18	13	7	14	7	6	1	16	23	"	19	17
41.0	18	14	8	14	7	5	1	16	22	"	19	15
41.0	20	13	8	14	7	5	1	15	21	"	20	21
41.5	19	15	8	14	7	5	1	15	21	"	19	18
46.0	19	14	8	14	7	5	1	15	21	"	18	17
46.0	18	15	8	15	7	6	1	16	23	"	17	17
47.0	19	14	8	14	7	4	1	15	20	"	19	15
48.0	20	14	8	13	7	5	1	16	22	"	19	20
48.5	19	14	8	15	7	5	1	16	22	"		18
51.0	18	14	8	15	7	7	1	18	26	"	17	18
54.5	19	14	8	14	7	6	1	15	22	"	20	20
86.8	18	16	8	14	7	7	1	17	25	"	18	19
121.3	18	15	8	13	7	9	1	16	26	"	16	11
200.9	18	15	8	13	7	9	1	17	27	"	14	18

[1] Cleared and stained.

of the Mediterranean (De Buen, 1930 and 1932) and the Gulf of Mexico (Klawe and Shimada, 1959).

They were assigned to the genus *Sarda* because vertebral counts fell within the range of 44 to 46 noted for adults. All other scombroids have either more or fewer vertebrae than *Sarda*. The vertebral counts were determined from X-rays for some and by using the clearing and staining technique of Clothier (1950) on other selected individuals.

Specific identity was determined on the basis of the number, size and shape of the lower jaw teeth and the number of anterior rakers and teeth (posterior rakers) on the first gill arch. In all cases, lower jaw dentition was similar to that of adult *S. chiliensis*, which is distinct from *S. velox*. The former has 14 to 25 acute, conical teeth varying in size and irregularly spaced, while the latter has 12 to 15 teeth of uniform size and even distribution.

With but a single exception, all specimens 29 mm. and longer had gill raker counts falling within the range of 19 to 27 reported for adult *S. chiliensis*. Total raker count is diagnostically useful for specimens longer than 24 mm. because at this stage of development, *S. chiliensis* exceed the 14-raker maximum noted for mature *S. velox* (Table 3).

The numerous well-developed posterior rakers or gill teeth on the first gill arch on all fish longer than 38 mm. further distinguished them from *S. velox*, which, according to Godsil (1955) have only a few rudimentary gill teeth on the upper limb and at the angle.

Pertinent meristic characteristics revealed by clearing and staining were: a count of the precaudal and caudal vertebrae; the position (number) of the vertebra supporting the first complete haemal arch; and, the number of teeth on the palatine (Table 4).

Of these, only the palatine teeth were not used for separating the two bonitos, since, according to Godsil (1955), their numbers overlap in adults. Godsil's studies on *S. velox* were not exhaustive however, and future studies may show the number of palatine teeth actually are of diagnostic value, particularly in the young. Therefore, the numbers observed in the four cleared and stained specimens have been included. The low counts, 5 to 7, indicate *S. chiliensis* does not have a full complement of palatine teeth at the beginning of its juvenile period.

TABLE 4

Meristic Characteristics of the Vertebral Column of **Sarda chiliensis** Derived from Four Cleared and Stained Specimens

Character	Fork length in mm.			
	25	31	32	41
Number of vertebrae	**45**	**46**	**46**	**45**
Precaudal	24	25	24	24
Caudal	21	21	22	21
Vertebra supporting first complete haemal arch	11	14	13	13
Number of palatine teeth				
Left	5	6	7	7
Right	5	6	7	7

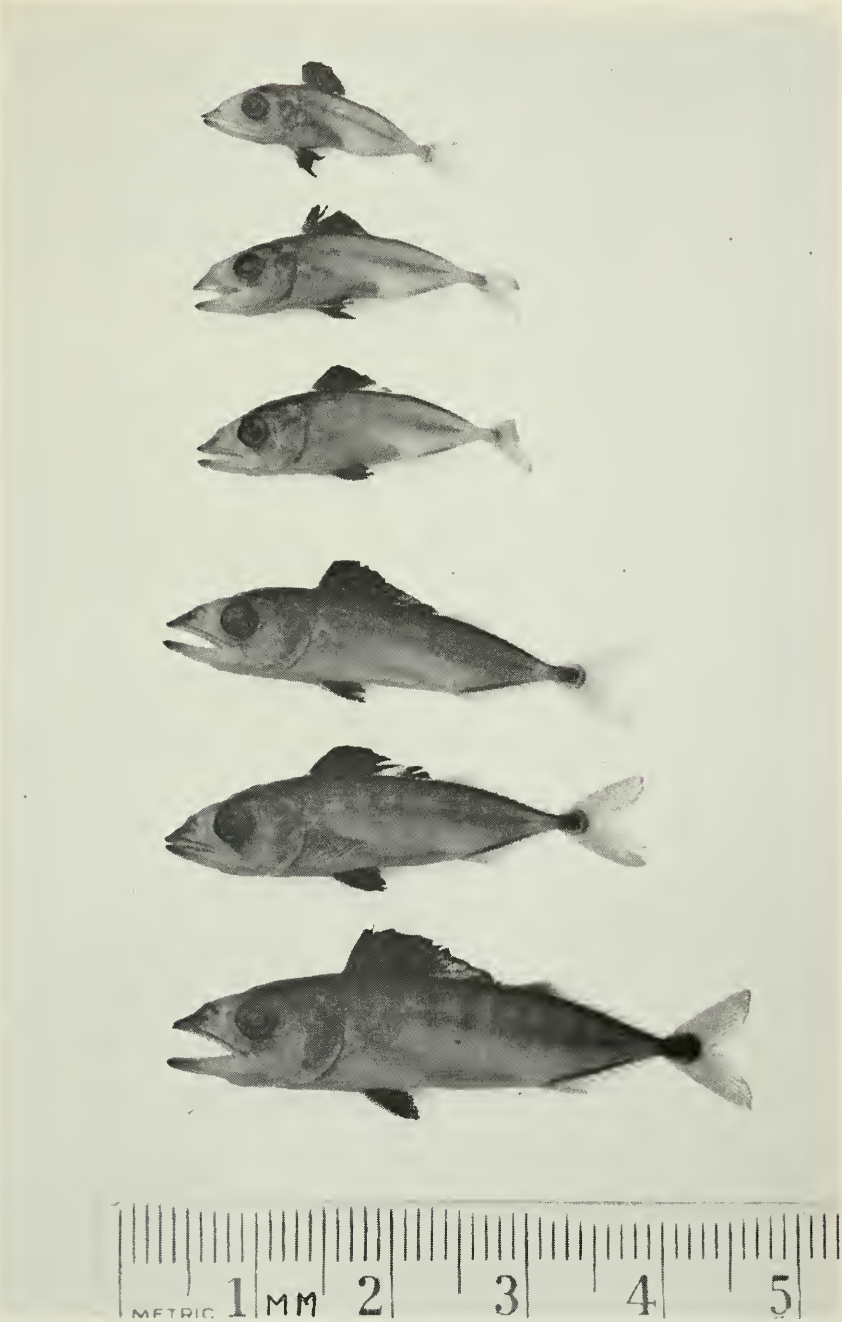

FIGURE 2. An array of postlarval *Sarda chiliensis* ranging from 19 to 41 mm. fork length. *Photo by Jack W. Schott.*

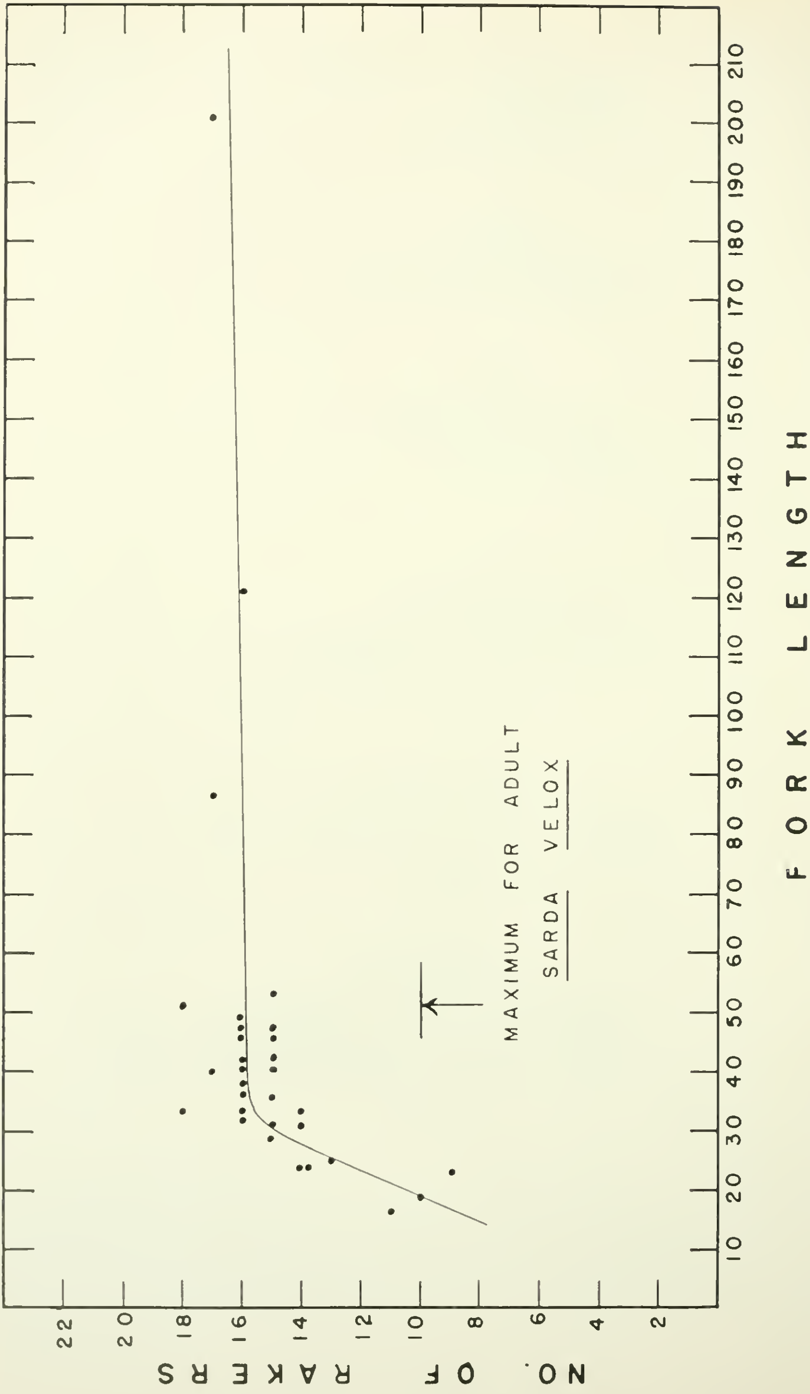

FIGURE 3. Graphic illustration of transition from postlarval to juvenile stage for *Sarda chiliensis* in which the number of anterior rakers on the lower limb of the first gill arch is plotted against fork length in millimeters. The trend was fitted by eye.

In general, there was a rather smooth progression in anatomical development from the smallest specimen (16.7 mm. fork length) through the juveniles, to the young adult (Figure 2). A marked change takes place at about 20 mm. when the postlarval 'look' is lost and the juvenile form emerges. The true juvenile stage, when most of the adult characteristics become firmly established, does not occur until they reach lengths of 32 to 40 mm. Figure 3 graphically illustrates the transition into the juvenile stage with respect to rakers on the lower limb of the first gill arch.

POSTLARVAL STAGE
INDIVIDUALS 16.7 TO 40.0 mm. FORK LENGTH

In lateral view, the body of the 16.7 and 19.0 mm. specimens is bluntly fusiform (Figure 4). The conical head is relatively large, comprising 38.9 percent of the body length at 16.7 mm. Although the eye is conspicuous, it is not disproportionately large. There are four or five small blunt spines above the eye. The posterior end of the maxillary reaches to or slightly past an imaginary vertical line which passes through the center of the eye. The acute conical teeth are in a single row, vary in size, and are irregularly spaced. Some of the teeth are slightly curved. The lower jaw teeth increase in numbers as the bonito grows. Counts made on the left side ranged from 13 to 17. The 25 recorded for a 32 mm. cleared and stained specimen included some not normally visible in unstained specimens.

The eight spines at the posterior edge of the preoperculum project distally and posteriorly and are very prominent during this stage of development. The largest spine occurs at the angle of the preoperculum, while the others are unequally distributed about it—three above and four below. These spines decrease progressively in size away from the large spine at the angle. At the anterior base of the three largest preopercular spines are three small blunt spines which project distally. By the end of the postlarval period, the developing preopercular bone engulfs all except the three largest spines at its angle; these project well ahead of it forming a base or framework for future growth.

Three or four relatively short posttemporal spines project distally and posteriorally. In the larger fish of this group, 30 to 40 mm. in length, they have become quite obscure, appearing as slight protuberances.

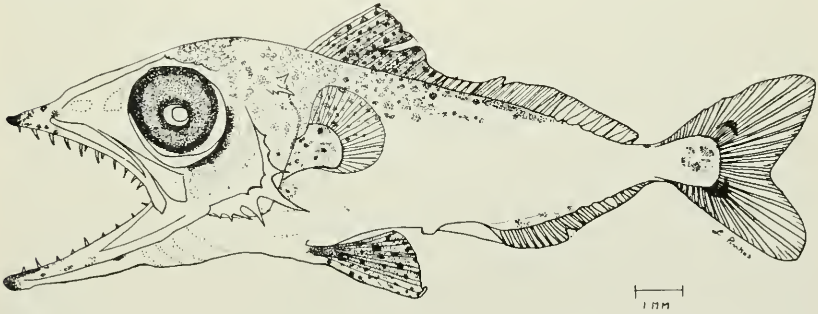

FIGURE 4. *Sarda chiliensis* 16.7 mm. fork length dipnetted off Cape San Lucas, Baja California, April 11, 1955.

The dorsal fin during this period of development is a single uninterrupted fin composed of spines and rays. The adult morphology of a first and second dorsal fin and eight finlets is, however, easily discernable in the earliest stages. These sections become more distinct with growth. In this report the first dorsal fin is defined as that group of spines preceding the second abrupt elongation of spines and rays. This usually occurs with spine number 20, ranging between 19 and 21. Thus, the first dorsal fin is composed of spines while the second dorsal fin contains one or two spines along with the soft rays. The fin ray counts are reported as total elements for each fin (Table 3) because in the formative stages it is difficult to distinguish spines from soft rays. Reporting total elements facilitates comparisons with other studies (Godsil, 1955 and Matsumoto, 1958).

Although the first and second dorsal fins are continuous they appear distinct because spines XVII to XIX are considerably shorter than those both anterior and posterior to them. The marginal outline of the first dorsal fin, when erect, is convex with a slight concavity in the area of spines IX and X.

The pectoral and pelvic fins are moderately developed. The insertion of the pectoral fin occurs just below the lateral line and an imaginary vertical line drawn through it would also pass through the insertion of the first dorsal fin. The pelvic fins are thoracic; inserted close to the ventral midline, beneath and slightly posterior to the pectoral base. The eight dorsal and seven anal finlets are discernable in all specimens, however, they are not completely separate. The insertion of the anal fin on the ventral midline is located approximately vertically beneath the middle of the second dorsal fin.

The caudal peduncle is devoid of protuberances on specimens shorter than 38 mm. At this point, both the caudal keel and the pseudofins (Herald, 1951) begin to develop as simple, narrow, semitranslucent, cartilagenous-like ridges. The two keels are located along the lateral midline, one on each side. The four pseudofins occur in pairs, two on each side; one above the lateral line and one below it. The long axes of the pseudofins are oriented in a general anterior-posterior direction.

The most outstanding and unique feature in the postlarvae of *Sarda chiliensis* are the all-black pelvics and the almost all-black first dorsal fin. In the smallest specimen, 16.7 mm. long, this characteristic pattern is fully developed and it persists into the juvenile stage.

An irregular clear area is usually found on the first dorsal fin between spines IX to XIV. Since the area is not completely devoid of melanophores, varying in degree from specimen to specimen, the general appearance is that of a clear to dusky patch against a dark background. The remaining fins: second dorsal, pectorals, anal, caudal and all the finlets are devoid of pigmentation, appearing translucent.

The eye is the most heavily pigmented organ in the head region, appearing almost black in preserved specimens. The brain area is only moderately covered with melanophores. Other pigmented areas, which vary in intensity, occur at the tip of the snout and lower jaw, below the eye, at the nape, and at the base of the caudal fin.

The 7 to 12 vertical dusky bars on the body are also a distinctive feature of the pigmentation. They vary in width, length and location;

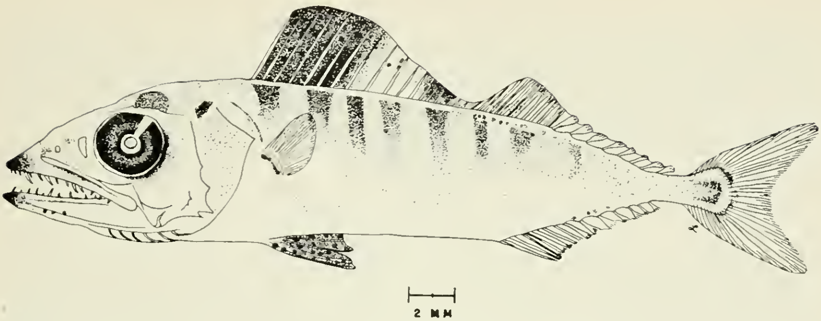

FIGURE 5. *Sarda chiliensis* 33.0 mm. fork length dipnetted off Cape San Lucas, Baja California, July 11, 1956.

the first occurs either just behind the nape or under the first few dorsal spines (Figure 5).

JUVENILE STAGE
INDIVIDUALS 40 TO ABOUT 200 mm. FORK LENGTH

The body, in lateral aspect, is typically fusiform; not as blunt as in the postlarval stage but more elongate, as in a young adult. The head comprises 31.7 percent of the body length at 41.0 mm. and is still relatively large. With growth, however, the ratio decreases proportionately until a ratio of 27.6 percent is obtained for subadults.

The number of teeth in the left half of the lower jaw ranges from 15 to 22, increasing slightly as the fish becomes larger.

The growing and ossifying preopercular bone has engulfed the three remaining preopercular spines at about 60 mm. in length. Beyond this point they are often discernible because the developing preopercular bone is translucent. The posttemporal spines disappear completely in this stage of development.

In the larger specimens it was possible to differentiate the spines from the rays in the dorsal and anal fins. Counts of XVIII—I,14 to 15—VII and II,12—VII, compare favorably with those reported by Hildebrand (1946) and Clothier (1950) for adult *S. chiliensis*. The finlets become free from a connecting membrane at about 50 mm. in length.

Throughout the juvenile stage the first dorsal fin retains the generally black appearance. With growth, however, there is a gradual change, the spines become clear and the pigment on the membranes increases in intensity, giving the fin the appearance of being streaked with white. The clear area, evident during the postlarval period, occasionally lingers on—at times even into the subadult.

The pelvic fins were heavily pigmented in all specimens shorter than about 55 mm. In specimens 55 to 85 mm. long, the black pigmentation at the distal portion was replaced by white, which progressed with growth towards the fin's insertion. In the late juvenile period the pelvic fins were all white except for a black spot at their base.

Early in the juvenile stages, black pigment begins to accumulate near the base of the second dorsal fin and with size gradually increases

in degree and extent. Later the other fins begin to develop characteristic color patterns. The pectoral fins, viewed best when extended, become black above and white below. The anal fin and anal finlets become white while the dorsal finlets darken. The caudal fin appears dusky with a rather heavily pigmented area at the base. Chronologically the finlets are the last to become pigmented.

DISCUSSION

Young of *S. chiliensis*, longer than 16.7 mm., can be distinguished from all other scombroid larvae of similar sizes, with the possible exception of *S. velox*, by the distinctive black pigmentation of the first dorsal and pelvic fins. Although smaller specimens were not available in this study, it is probable, from the work of Barnhart (*op. cit.*), that this distinctive pigmentation develops almost immediately after hatching. He noted and depicted groups of melanophores on the dorsal finfold and in the area of the pelvic fins in newly-hatched larvae, 3.5 mm. long.

The four or five spines above the eye in the postlarval stages are also distinctive and perhaps unique. Examination of a number of other genera of scombroid larvae in our collections and a survey of the literature failed to reveal similar spines.

Sarda chiliensis, 24.0 mm. long and longer, can be distinguished from *S. velox* of similar sizes by the greater number of lower jaw teeth, 14 to 25 versus 12 to 15; the greater number of anterior gill rakers, 19 to 27 versus 11 to 14; and the presence of numerous well-defined posterior gill teeth—*S. velox* has but a few rudimentary ones.

SUMMARY

1. Postlarvae and juvenile *Sarda chiliensis*, 16.7 to 200.9 mm. are described and illustrated and the localities of their capture recorded.
2. Specific identification was based upon: number of vertebrae; kind and number of teeth in the lower jaw; number of rakers on the lower limb of the first gill arch; and the presence of posterior gill teeth. All of these characteristics serve to distinguish *S. chiliensis* from *S. velox*, the other eastern Pacific bonito.
3. Two unique and distinctive features of diagnostic value in separating *Sarda chiliensis* from other larval scombrids (except *S. velox*) are: all-black pelvic fins in combination with an almost all-black first dorsal fin; and the four or five spines above each eye of the postlarvae.

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THE INFLUENCES OF INORGANIC SEDIMENT ON THE AQUATIC LIFE OF STREAMS[1]

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INTRODUCTION

California's tremendous population increase since World War II has created serious problems for those charged with the conservation of its natural resources. Fisheries resources dependent upon the maintenance of natural conditions are threatened with significant damage—if not complete destruction—by the construction of dams, by pollution, and by erosion. These problems are neither new nor unique. Valuable stream fisheries have been lost before to these three horsemen of civilization.

Erosion is probably the most insidious of the three, for it is often unspectacular and goes unnoticed from one year to the next. The damage is often widespread and permanent. Aitken (1936) recorded changes in fish fauna of Iowa streams. Streams supporting trout, smallmouth bass, and other clean-water forms were transformed to streams containing rough fish or mud-loving forms. This change was attributed to erosion which transformed cold, clear streams to warm, turbid streams. Ellis (1931a) states that the outstanding factor producing changes in the Mississippi River fauna seems to be that of erosion silt.

In summarizing man-made influences on the fish fauna of Ohio for the period 1750 to 1950, Trautman (1957, p. 29) states:

[1] Submitted July, 1960.

> "These drastic modifications have considerably modified the fish fauna, changing it from a species complex, dominated by fishes requiring clear and/or vegetated waters to one dominated by those species tolerant of much turbidity of water and of bottoms composed of clayey silts. There has been a shift from large fishes of great food value to smaller species unfit as human food, or larger fishes of inferior quality as human food."

Concerning the role of silt pollution in the disappearance of Atlantic salmon from many of its native haunts, Wolf (1950) declares:

> "And now we have come to the problem of the silting down of the spawning grounds and its effect on the salmon production. This silting down is certainly an important factor. Wherever such a thing happens, it is hardly necessary to look for any other reasons for the total disappearance of the salmon. A very great part of the region around the former salmon rivers flowing to Lake Ontario was cultivated during the course of the last century. Already in the beginning of this article, it has been mentioned how the natural cover of vegetation continually diminished as cultivation went on and how the lands slowly lost their protection against the forces of erosion. As a consequence, the soil was washed down into the rivers, where it became silt. . . ."
>
> "As a summary, we could say that, although many factors contributed to diminish the power of resistance of the salmon stock, the real reason for its extinction has been the silting down caused by the uncontrolled cultivation. Again it must be emphasized that this cultivation had very little value for the future. During a relatively short period, it gave a good yield but later had to be given up. The result to-day seems to be only negative. The value of the region for forestry has declined, and an abundance of salmon has been lost. This bitter experience has perhaps had one good effect: it is possible that it may teach us to control cultivation and prevent a repetition of this wasteful process."

Californians and especially those charged with land or resource management must realize that their state is not immune.

SCOPE

This report is essentially a review of investigations made of the effects of inorganic sediment on the aquatic life of streams.

It is not a complete literature review but rather a summary of most of the pertinent investigations that we believe will assist the fisheries worker faced with sediment problems. No references are included on studies of any type of chemical pollutants even though the waste material contained large amounts of sediment, such as when tailings from heavy-metal mining operations are discharged to waterways. In such cases, the physical influence of inorganic sediment on aquatic life cannot readily be separated from damage done by toxic heavy metals in solution. This is true also for chemicals used in floatation processes during mineral extraction.

Of fundamental importance in comprehending the modes by which sediment modifies the aquatic habitat is knowledge of the physical nature of sediment and its movements in flowing waters. Sediment arises from a multitude of soil types, varies greatly in shape, size and density, and enters flowing waters which vary in velocity, temperature, flow, and turbulence. The complex problems involved here are studied by the geologist, the soil scientist, and the hydraulic engineer. Fisheries biologists working on sedimentation problems should be aware of this work and familiar with the basic concepts of erosion and sedimentation, but a review of the literature on this subject was beyond the scope of this report. We mention it here only to mark its extreme importance.

For comprehensive reviews of the problems created by sediment in our waterways which confront land and water uses other than aquatic life, see Einstein and Johnson (1956) and Gleason (1958). See Cordone (1956) for a review of the literature on the effects of logging on fish production.

Detailed physical descriptions of how rainfall and runoff erode soil were presented by Osborn (1955) and Gottschalk and Jones (1955). These reports are helpful in understanding the factors governing sediment movement into or within a streambed.

DIRECT EFFECT OF SEDIMENT UPON FISHES

Fisheries workers seeking an answer to the question, "Are fish directly harmed by inorganic sediment?", have achieved a variety of replies. This is not surprising, considering the variations in sediment types and sizes, in environmental conditions, and in the fishes themselves. Unfortunately, all of the factors that influence the reactions of the fish can seldom be measured in the field, and carefully controlled experiments subjecting fish to sediment are rare.

The work of Wallen (1951) is an exception. He conducted controlled aquarium investigations on the direct effect of turbidity on warmwater fishes. Turbidity was induced by use of silt and montmorillonite clay. Particle size ranged from coarse silt to very fine clay. No salmonids were included in the tests. The results of this study are of sufficient import to bear repeating:

"1. Tests were made to determine the direct effect of montmorillonite clay turbidity on 380 fishes involving 16 species.

"2. Observable behavioral reactions that appeared as a turbidity effect did not develop until concentrations of turbidity neared 20,000 ppm., and in one species reactions did not appear until turbidities reached 100,000 ppm.

"3. Behavioral reactions were governed by concentrations of turbidity and followed a definite pattern from inception to death. The reactions included (1) momentary swimming at the surface and gulping air and water, (2) leaning toward one side or the other while remaining at the surface for several minutes, (3) floating on one side for up to 30 minutes with an occasional swimming movement and (4) floating with only occasional, feeble, opercular and pectoral fin movements until terminated by death of the fishes.

"4. Most individuals of all species used endured exposures to more than 100,000 ppm. of turbidity for a week or longer, but these same fishes finally died at turbidities of 175,000 to 225,000 ppm.

"5. Lethal turbidities caused the death of fishes within 15 minutes to two hours after the onset of exposure.

"6. Fishes that succumbed to turbidity had opercular cavities and gill filaments clogged with silty clay particles from the water.

"7. Important conditions enabling fishes to avoid clogging of gills in sublethally turbid waters were (1) maintenance of movements and (2) aeration of the water.

"8. The results of this work indicate that the direct effect of montmorillonite clay turbidity is not a lethal condition in the life of juvenile to adult fishes at turbidities found in nature."

Wallen found no evidence of gill injury even though the gills were blanketed with a layer of silt and the opercular cavities matted with the material. All organs appeared normal. Arteries and veins were not congested, and no unusual amount of mucus was secreted by the gills.

Ellis (1937) also examined fishes whose gills were coated with sediment. His description (page 401) of the coating responsible for death agrees with that observed by Wallen, ". . . the precipitate coated the gill filaments and filled the filament interspaces so that the water pumped through the mouth and onto the gills for the aeration of the blood could not reach the cells of the gill filaments. Consequently, the aeration of the blood with its accompanying gas exchanges was prevented, and sooner or later death followed from a combination of anoxemia and carbon-dioxide retention." It appears that coating of gills by silt impairs the functions of circulation, respiration, excretion, and probably salt balance. In our review of the literature, we turned up no reports of equally comprehensive tests on salmonids.

Griffin (1938) conducted laboratory tests with young cutthroat trout and king salmon in connection with H. B. Ward's famous investigation (1938a and 1938b) on the effects of placer mining on the Rogue River in Oregon. The tests were made on young cutthroat trout and king salmon held in water recirculated through troughs. Silt from a placer operation was introduced into the troughs. The cutthroat trout test lasted 30 days with a 56 percent survival in the sediment trough, compared to a 10 percent survival in the control. Turbidity reached 3,500 ppm. at daily stirring, but was maintained between 360 and 600 ppm. during the remainder of the day. The experiment with king salmon ended in 28 days with a survival of 88 percent of fish in muddy water, compared to 36 percent for the controls. The maximum load at stirring ranged from 3,100 to 6,500 ppm., and the constant load from 300 to 480 ppm. For a number of reasons, adequate control conditions were not maintained during the experiments. More extensive tests were called for but, as the author indicates, this was impossible due to the limited time and apparatus available.

Griffin concludes, "The results of the experiments indicate that young trout and salmon are not directly injured by living for considerable periods of time in water which carries so much soil sediment

that it is made extremely muddy and opaque. They also indicate that cutthroat trout and salmon fingerlings can feed and grow apparently well in very muddy water.''

Before the significance of these conclusions can be appreciated, it must be remembered that the duration of the tests were 20 and 28 days and that no attempt was made to compare or analyze growth or condition of the test fish.

Some of the statements in this report have been misinterpreted, and Smith (1940) has clarified the matter.

> ''Griffin, in Appendix B to Ward's report (1938a), gave the results of an experiment which seems to prove, according to the *California Mining Journal*, October, 1938, that 'young fish thrive on mud.' In those experiments, cutthroat trout and chinook salmon fingerlings were held in hatchery troughs, some containing clear water and others muddy water. In both species, the survival was greater in muddy than in clear water. However, in each of the two tanks of clear water, the heaviest loss occurred during the first four days of the experiment. Griffin attributed the heavy loss to the fact that the fish in clear water were able to see better and were so frightened by activity near the tanks that they dashed against the walls and injured themselves. Whatever the cause, a mortality as large as forty-six out of seventy-five salmon fingerlings in four days must be attributed to some unusual factor which would not affect wild fish. In fact, ten out of the forty-six fingerlings died because they leaped out of the tank. Consequently it would be better to compare survivals after the fourth day. When this is done it appears that the salmon mortality was higher in muddy water, 12.2 per cent, than in clear water, 6.9 per cent. Results of the experiments with the cutthroat trout were the reverse; mortality was 42.9 per cent in muddy water and 85.7 per cent in clear water, disregarding losses during the first four days. Both percentages of mortality for cutthroat trout are so abnormally high and the number of fish used in the experiment so small (fifty and forty at the start) that the difference between the percentages has no significance. The only conclusion that may be drawn from the two experiments is that salmon and trout fingerlings can survive and take food for a few weeks in muddy water. Griffin himself stated practically the same thing, but unfortunately he presented his data in such a way that they can be misinterpreted easily. Incidentally, the fact that fish can find artificial food in muddy water would not help them much in streams where silt has smothered the natural food organisms.''

A field experiment on the direct effect of turbidity on cutthroat trout was conducted by Bachmann (1959). Two enclosed 30-foot study sections were established on Silver Creek, Idaho, with six fish placed in the lower section and five in the upper. The lower section was subjected to artificially created silt turbidities for two hours. Average maximum turbidity was 35 ppm. Fish in the turbid section showed no distress and suffered no mortality. However, the control fish fed actively throughout the study period, while the test fish ceased feeding and moved to cover.

Another field experiment on the survival of trout when exposed to higher turbidity created by a gold dredge on the Powder River was carried out by Campbell (1954). Rainbow trout fingerlings were used in the tests. The control was located in an unpolluted tributary with the test fish placed one and one-half miles below the dredge. Turbidity ranged from 1,000 to 2,500 ppm. Losses of trout in the silty area reached 57 percent within a 20-day period compared to 9.5 percent in the control. The presence of bottom fauna, though drastically reduced, during dredge operation indicated the absence of toxic substances.

Pautzke (1938) conducted live car experiments with steelhead trout in Cedar River and cutthroat trout in Squalicum Creek, and they revealed that the combined action of sand, slate, and coal particles carried in suspension were lethal to all test fish in two and one-half hours and one-half hour, respectively. "Examination of the dead fish disclosed heavy secretions of mucus covering the fish and the gills. Solid masses of coal dust and slate particles adhered to the mucus." The material is discharged to the streams during coal washing operations. The coal chiefly mined was semi-bituminous in type, low in sulphur content, and high in waste materials such as slate and sand. Fish were kept overnight in water pumped from the mine to determine if it was causing the mortality, but no losses occurred.

We have found many statements in the literature that silt is directly harmful to fishes by interference with normal gill functions.

Ellis (1944, p. 12) in a report setting down water purity standards for freshwater fishes summarized the results of a series of experiments conducted by the U. S. Bureau of Fisheries:

> ". . . Particulate matter of a hardness greater than one if held in suspension by current action or otherwise will injure the gills and other delicate exposed structures of fishes, molluscs and insects if the particles be large enough. A large series of experiments at the Columbia laboratories have demonstrated that rock powders, blast-furnace slags, cinder particles, and even coal washings will cut and injure both fish gills and the mantle and gills of unionid molluscs if the particles be larger than those which will pass through a 1,000-mesh (to the inch) screen. In the actual tests the larger the particles, and the greater their hardness and angularity, the greater the possibility of injury to gill structures. These abrasive injuries not only cut the gills but provide entrance for disease organisms. Even erosion silt which will pass through a 1,000-mesh screen produces copious flows of mucous from bivalve molluscs and increases the secretion of slime by fish gills if the quantity in suspension be great enough."

Kemp (1949) stated that mud or silt in suspension will clog or cut the gills of many fish and mollusks and he considered 3,000 ppm. dangerous, if maintained for a period of ten days. As an example, he cited a flood in 1936 which created a turbidity of 6,000 ppm. in the Potomac River and lasted 15 days. The fish kill was large and the oyster beds were severely damaged.

Trautman (1933) maintained that gravel pit washings and soil washings from corn fields, ". . . clog or cover the gills of fishes and so prevent respiration that death results; . . ."

Reliable as these and other observations may be, the fact remains that little data are available to support any universal answer on whether or not sediment is directly harmful to fish. The fisheries worker investigating this problem must be prepared to look very carefully at all conditions before he blames the sediment itself for direct damage to fishes.

The presence of toxic water complicates the picture. Ellis (1937) pointed out that healthy and uninjured fish can move through very muddy water since the continuous secretion of mucus washes away the sediment particles. However, when toxic chemicals injure the gills or alter the flow of mucus, the addition of suspended silt may aggravate gill damage through increased abrasive or matting action.

We observed an example of this in 1957 when a holding pond for a clay products plant washed away into the Mokelumne River near Camanche, California. The same rains which washed away the pond dike caused highly toxic water containing copper and zinc to flow into the river from an abandoned mine five miles upstream. Observations by local wardens suggested that the concentration of clay in the river was killing fish, but subsequent bioassays showed only that the fish died more rapidly when exposed to the suspended clay and the toxic water than they did in the toxic water alone.

The fisheries worker is usually presented with less dramatic cases than this. Our literature review and experience suggests that the question, "Is the sediment directly harmful to fish?", cannot really be answered without knowing more than usually is known. In most cases, indirect damage to the fish population through destruction of the food supply, eggs or alevins, or changes in the habitat probably occur long before the adult fish are directly harmed. Unless he is prepared to conduct exhaustive tests, the fisheries worker would do well to leave the question unanswered and base his actions on the indirect effects of sediment and subsequent changes in the fish population.

Of course, the fish do not have to be killed to be directly influenced. Sumner and Smith (1939) and Smith (1940) reported that king salmon avoided the muddy water of the Yuba River, California, in preference for the clear water of a relatively small tributary, containing about 1/25 of the flow of the Yuba. Salmon occurred in such concentrations that previously constructed redds were torn up. Where clear seepage flow created a clear streak along one side of the Yuba River, salmon again were attracted in more conspicuous numbers than to nearby spawning areas in the main river.

These two reports also mentioned the behavior of salmon in streams of Bristol Bay, Alaska, which carry a load of glacial silt. Salmon will swim through this silt, but always spawn in the clear side tributaries. Cooper (1956) noted that sockeye salmon migrate through the Fraser River during high turbidities but spawn in tributaries where turbidities are low.

The Washington Department of Fisheries (1959, p. 57) reported that the king salmon run in the Columbia River was deterred by excessive silting below Bonneville Dam with near disastrous results because the fish were held up in an area where they were subject to unusual harvest.

The fact that king salmon adults react to turbid waters seems clear. The difficulty of making observations of fish in turbid water has prevented very exact definition of just what the reactions are.

INFLUENCES OF SEDIMENT UPON EGGS AND ALEVINS

Sediment deposition in streams has for years been thought to be damaging to fish eggs buried there. The problem has been investigated rather extensively.

One of the earliest published experiments in the hatching of fish eggs in gravel was reported by Harrison (1923). He described the results of tests conducted in British Columbia with eyed eggs of the sockeye salmon as follows:

Number planted	*Description of nest*	*Number hatched*
500	Gravel from size of pea to hickory nut, some clean sand	350
500	Same as above with top coating of silt, ½ inch deep	325
500	Fine gravel, sand, and small amount of clay in sand	200
500	Fine gravel and much clay or mud in sand	170
500	Gravel from size of hickory nut to walnut, very little sand, no clay or top covering of silt	420

Hobbs (1937) conducted a pioneering study of natural reproduction of king salmon, and brown and rainbow trout in several New Zealand streams. His observations on mortality of eggs in the gravel, led him to state (page 75) that, "The bulk of losses which, irrespective of species of fish, occur in varying intensity in different streams and in different redds of the same streams are attributed to a common factor [sediment] . . . where redds are very clean losses are very slight. Where redds are very dirty losses are heavy."

Hobbs sampled the sediment in redds and directly correlated mortality with amounts of material that would pass through a 0.03-inch screen. Differences of only a few percent appeared to greatly affect mortality. Relatively small amounts (four percent) were damaging. He states (page 75), "There is sufficient evidence to show that where permeability is low there is a greater loss than where, other conditions being equal, the redd material is more permeable."

While Hobbs carefully explained the probability that the losses were directly due to reduction in amounts of oxygen reaching the eggs, he honestly states that his data do not furnish evidence of this. He was able to define the bulk of the losses as occurring before eyeing, when the egg was between 10 and 20 percent of its way toward completing development. Silt deposition during the eyed stage resulted in lower metabolic rates. Hobbs states that it is quite common for a crust of silt to be formed over the top of a redd. This did little harm unless floods with turbid waters increased the penetration of fine material into the egg pocket of the redd.

Hobbs found that king salmon eggs, buried at twice the depth of brown trout eggs, were less affected by silt. Not only were they protected from the silt because they were buried deeper, but they completed pre-eyed development before the worst floods. Rainbow trout spawned after the floods and they cleared silt from the streambed in the process of redd construction.

Sediment in these New Zealand streams was introduced by natural causes, mostly flooding, and in certain observed cases was sufficient to cause unusual mortalities of eggs. In most cases the success of natural reproduction was excellent.

Although the experiments by Shapovalov (1937) were not designed to test the influence of silt on steelhead eggs, natural siltation entering the hatchery water supply provided such an opportunity. Two experiments were conducted comparing survival of eggs placed in gravel in a hatchery trough with eggs in the standard wire hatching basket in aquariums. During the first trial, heavy rains caused the water to become muddy for nine days. Percentage survival to time of emergence during the first trial was 29.8 percent for the eggs buried in gravel and 80 percent for the control lot held in a standard hatchery basket. Clear water conditions existed during the second trial and the egg survival was 79.9 percent in the basket and 81.7 percent in the gravel. The author states, "The exact effect [of silt] on the eggs in the gravel cannot be told, except by inference from the survival data, but it was observed that there was a heavy coating of silt on top of the gravel and down the sides of the aquarium, reaching the eggs. . . It may be significant that in the control lot the largest number of dead eggs was removed during the three days following the period of muddy water." In the summary, Shapovalov maintained that under good conditions in nature the percentage of eggs which are fertilized, hatch, and emerge from the gravel is rather high but may be quite low under adverse conditions such as silting caused by flooding, as here, or mining.

Shapovalov and Berrian (1940), as a follow-up to the 1937 tests, conducted controlled experiments on the hatching of silver salmon eggs. The experimental lot was buried in gravel in a hatchery trough, with the control lot placed in a standard wire hatching basket in a similar trough. Survival to emergence was about 10 percent from the gravel and 50 percent from the control. Concerning this poor survival, the authors state, "In the present experiment some of the worst floods ever experienced occurred while the eggs were in the gravel (especially just after the eyed stage was reached), and the water in the hatchery troughs was laden with silt . . ., when the experiment was concluded, the gravel was removed by hand and a considerable amount of silt was found throughout it. A large number of eggs that had developed partially was found also. There is every reason to believe that they were smothered by the large quantities of silt that had settled around them."

Shapovalov and Taft (1954) presented the results of extensive studies on Waddell Creek, California. They stated (page 274), "As in the case of the silver salmon, silting occurring between fertilization and hatching is probably the principal cause of pre-hatching losses."

Among the investigations on the effect of mining silt on the yield of fry from salmon spawning beds is that by Shaw and Maga (1943). Silver salmon were used in the tests which were conducted at the Brookdale Fish Hatchery, Santa Cruz County, California. The summary and conclusions of this report are repeated below:

> "1. Salmon eggs hatched in the usual manner by placing a basket of eggs in the flowing water of a hatchery trough produced a yield of 79.9% fry with 733 temperature units.

"2. Salmon eggs placed in prepared gravel beds constructed in a hatchery trough and receiving only normal hatchery water produced a maximum yield of 25.4% and an average of 16.2% fry. Occasional silting of the water supply due to storms may have lowered the yield. To first emergence from the gravel 992 temperature units were required.

"3. Salmon eggs in prepared gravel beds that received mining silt for intervals of 2 to 72 days beginning with the initial stages of incubation produced a maximum yield of 2.4% and an average yield of only 1.16% fry. A total of 1385 temperature units were required to first emergence from the gravel. Many of the undeveloped eggs remaining in the gravel were preserved with a coating of silt. Fry that died or failed to emerge outnumbered those that worked through the gravel.

"4. Salmon eggs in prepared gravel beds that only received mining silt during the emergence period produced a yield of 13.4% fry but earlier silt additions extending back into the incubation period produced progressively lower yields which reached zero with silting at the beginning of the incubation period. In this series the number of undeveloped eggs that were coated and preserved with silt increased steadily with earlier and longer periods of silt addition. Very few fish that hatched failed to emerge but many fry apparently worked forward through a screen rather than upward through the gravel and deposited silt.

"From the data presented in this paper it is evident that the yield of fry from eggs hatched in gravel beds supplied with normal hatchery water is far below that attained by the usual procedure of basket hatching in flowing water. The experiments further show that mine silt deposited on gravel spawning beds during either the early or later stages of incubation results in negligible yields of fry and is therefore a serious menace to natural propogation.

"From a practical standpoint this damage to spawning beds would occur when mining silt enters a stream at times other than storm periods when the water velocity is insufficient to carry the sediment in suspension. It is a well-known fact that the velocities necessary to dislodge deposited particles are far greater than the velocities required to carry the same particles in suspension. For this reason natural stream turbidity is largely limited to those periods when storm water causes erosion. During these periods stream flows in areas suitable for steelhead, trout, or salmon spawning are sufficient to prevent bottom deposits of natural erosion silt and damage to eggs in the gravel is minimized. Thus, while mining silt may be natural material, its presence in waterways during nonerosion periods results in bottom deposition which is unnatural and damaging."

In 1952 several careful studies were made by the Washington Department of Fisheries of the effects of a large clay slide near Hatterman, Washington, on the North Fork of the Stillaguamish River. The studies were reported by Heg (1952) and Hertzog (1953). The slide consisted mostly of fine material about 90 percent of which was small enough to pass through a number 200-mesh sieve. It was calculated to have

increased turbidity of the stream by about 35 ppm. Experiments indicated that less than 15 percent of the introduced material settled out in quiescent areas of the stream.

Steelhead eggs were deposited in plastic mesh bags at various distances below the slide. The silting from the slide reduced successful development of eggs and fry for a distance of less than one mile downstream. In that area, sediment deposits caused losses of 50 to 100 percent of the eggs observed.

The U.S. Fish and Wildlife Service has been conducting survival studies on the eggs of king salmon in Mill Creek, California (Gangmark and Broad, 1955 and 1956). Eggs were placed in containers and buried in spawning riffles. The most obvious factor affecting egg survival in the experiments was flooding. A close correlation exists between egg losses and severe freshets. Since turbidity and siltation occurred simultaneously with flooding, it would seem difficult to separate the effect of each; however, actual physical destruction of the spawning beds by scouring appeared to be the most important factor. Comments on the significance of silt in egg mortality appeared in both reports. Examinations of eggs found after a severe flood during the first test revealed that none of the embryos had survived the floods. "The shifting of the channel and the eroding and smothering action of silt and sand apparently caused a complete kill of the developing young salmon." In the second study a controlled flow area was included as a control not subject to severe scouring floods. "Eggs in the controlled flow area suffered mortalities from silt deposition only."

In the most recent report on their work at Mill Creek, California, Gangmark and Bakkala (1960) presented data to show a direct relationship between the velocity of seepage in gravel adjacent to planted king salmon eggs and the survival of those eggs. They measured the velocity of seepage water through the gravel with plastic standpipes, and the mortality of eggs by burying them in plastic containers in simulated redds 12 to 14 inches under the streambed. At velocities of more than 3.5 feet per second, between 5.8 and 2.9 percent of the eggs died. At velocities between 1.5 to 3.5, mortality ranged from 10.1 to 13.0 percent. At velocities of 0.5 to 1.5, mortality rates ranged from 24 to 40 percent.

The authors studied salmon production in an old streambed through which a channel was bulldozed and from which silt had been flushed. They compared production with that of Mill Creek itself:

> "Production of salmon in the Sacramento River area is limited by a variety of complex factors affecting the incubation of eggs, principal of which is the silt deposit left by heavy runoff of water that is typical of streams in this area. The means for alleviating damage resulting from heavy stream runoff appears to be control of the natural stream. In the assessment of factors that caused the superior production of salmon in the experimental controlled stream, the most impressive relationship in 1958 was the one associated with seepage rate in the gravel . . ."
>
> "Mortality to fry stage was 98.3 percent in the 1957-58 Mill Creek plants. This high mortality was obviously associated with reduced seepage in the gravel, which averaged only 0.3 foot per hour during most of the incubation season. In the controlled-flow area,

with seepage rates in the gravel averaging 3.5 feet per hour, survivals were either very good or very poor. Seventy-two percent of the samples averaged 75 percent production of salmon and were associated with good seepages. In the other extreme, 22 percent of the 100-egg samples were all dead—a result of poor seepages that were not always detected by the standpipes.''

Further evidence on the adverse influences of silt upon eggs in redds was uncovered by Neave (1947). He conducted an experiment on the efficiency of natural propagation of chum salmon in Nile Creek, British Columbia. A count of downstream migrant fry indicated high mortalities. He concluded that, ''Samples of eggs exhumed and examined during the winter of 1945-46 showed heavy mortality, most of which had occurred before the eggs had undergone any recognizable degree of development. Much of this loss could be attributed to silting of the bottom during periods of higher water, with resultant reduction of water circulation in the gravel.''

Williams Creek in British Columbia was the subject of an investigation of sockeye fry production by McDonald and Shepard (1955). Examination of redds in a newly silted section showed high mortality, probably due to suffocation. Following a stream improvement program which increased water flows and flushed out much of the silt, production of fry more than doubled.

An evaluation of the spawning of cutthroat trout in tributaries to Trappers Lake, Colorado, was made by Snyder (1959). One phase of the study was to establish quality standards for spawning sites. It was observed that, ''Areas of silt were frequently passed over by the spawning fish, even if the silt was covered by a thin layer of gravel. Fish were observed to dig through the thin gravel covering and stirring up the silt ladened substrate. When the silt was encountered by the fish, digging would continue forward as far as three feet, but eventually the site would be abandoned.''

Stuart (1953b and 1954) investigated factors which caused brown trout and Atlantic salmon to choose certain gravel beds for spawning in preference to others. Beds selected were found to be permeable to water. Consolidated gravels were avoided. The detailed characteristics of water currents were studied in the laboratory and their existence demonstrated in the field. The currents were found to run obliquely downward through the gravel, at right angles to the surface of the gravel bank. These currents enable the female to detect areas of suitable gravel. The downwardly directed currents are sufficiently strong to enable the fish to rest on the gravel surface without effort. The laboratory model demonstrated that the currents through the gravel are dependent chiefly on the gradient, and not the velocity, from pool to pool. The strongest currents exist below the apex of the gravel mound and decrease towards the middle of the pool where they cease.

Stuart (1953a) told of raking clean of silt the top 3 to 4 inches of gravel in an area which then was indistinguishable from a nearby known spawning bed. Nevertheless, it was still passed over by the spawning trout. He demonstrated the passage of water currents through the tails of pools, which were the favorite spawning sites, by the use of dyes. Trout appear to use this current, which can be quite strong, to

hold their position against the main current. This type of gravel is easy for the fish to excavate.

He also conducted laboratory experiments on the effects of silt on ova and alevins of brown trout in Scotland. This study was prompted by field investigations which revealed high mortality of ova in redds exposed to silting. Tests were made first with natural sediments and later with particles of carmine powder and finely divided carbon. Each material gave similar results.

It was found that the chorion lost its smooth and glossy exterior by attracting the finer silt particles and soon became completely covered by a dark coat of sediment. All early ova in this condition died without hatching. Eyed ova placed in turbid waters survived short exposure to these conditions (about 48 hours). Unlike the ova, newly-hatched alevins repelled suspended particles. This was accomplished through pectoral fin action and intermittent tail flexions. About 24 hours after hatching, the mouth and gills of the alevin began functioning to create a new hazard. Survival of the alevins at this stage depended primarily on the timing of the silt additions. The continuous addition of fresh sediment resulted in serious inflammation of the gill membranes which eventually caused death. Intermittent additions did not cause death. Older alevins were slightly more resistant. Alevins are, in general, better able to cope with siltation as they grow and move out of the gravel. Stuart concludes, as follows (page 35):

> "As we have seen, silt is not very dangerous in the normal stream if excess occurs only at intervals. The character of such normal streams can however be altered drastically by allowing the washings of quarries, gravel pits, mines, etc. to flow into streams untreated. In many cases the quantities allowed to enter the streams may be small and the material in suspension may in itself be of a non-toxic character, but as has been shown above, continuous application of small quantities over the redds may be much more detrimental to the welfare of the alevins than sudden flushes of large quantities."

Cooper (1956) conducted a thorough investigation of a probable damage to sockeye salmon runs in the Horsefly River, British Columbia, from proposed placer mining. The study was rather unique in that Cooper determined which materials would be deposited on the spawning beds, and then in the laboratory determined their probable effects upon the success of sockeye salmon egg and alevin survival. He:

1. Measured velocity, discharge, cross sections, slope, suspended sediment, and bottom sediments in the stream.
2. Determined that sediments transported in suspension were 0.3 mm. or less in diameter, and those transported as bed load were 32 mm. or less.
3. Estimated that with bed tractive force exhibited at low flows during the spawning periods, particles of 0.149 mm. or larger would accumulate on the spawning beds below the proposed mining operation.
4. Measured the particle size of sediment produced by a pilot placer mine.

5. Estimated that up to 9.7 percent of the material was small enough to pass as suspended sediment and that up to 57.7 percent was of a size capable of being transported as bed load through existing or potential salmon spawning areas downstream.
6. Tested the effects of sediment on rates of flow through river gravel and found that the reduction in such rates varies inversly with the particle size, the smaller particles being more effective in reducing velocity than the large ones. Silt and fine sand were very effective in clogging the gravel even in minor quantities.
7. Conducted experiments on the effects of sediment on survival of freshly fertilized sockeye salmon eggs buried in the gravel under controlled conditions. The application of sediment, particularly the fine materials, greatly reduced the percentage survival of the eggs.

Some significant statements from Cooper's work are quoted below: The first paragraph was taken from page 28, the second paragraph from page 52, and the third from page 54:

"In the normal course of events the principal source of sediment in streams in British Columbia is the spring freshet passing down the stream, with consequent bank wash and bed scour. As the freshet passes, the availability of transportable sediment decreases rapidly and in river reaches where the scour action is great, the bed is left relatively free of fine sediments and the water becomes relatively clear. This annual cycle is considered to be an essential characteristic of rivers in which the best salmon spawning grounds are located. However, if this normal pattern is altered by the artificial introduction of sediment during the period of declining discharge when such sediments would not normally be available to the river, some deposition of sediment will take place in the interstices of the bed materials, particularly near the river banks. It is not possible to estimate the bed material composition that will result from a given discharge and concentration of given particle sizes. In regions of large scour the amount of deposition of fine materials probably would be small, but it is a fair assumption that in order to preserve the stream bed in its normal condition, normal relationships between discharge and sediment size and concentration should be maintained."

"It may be concluded from this experiment that the deposition of sediment on gravel spawning beds would cause reduction in survival rates of eggs and alevins in proportion to the reduction in flow of water through the gravel. For a given type of gravel a certain apparent velocity is necessary to supply sufficient oxygen to all parts of the gravel to obtain maximum survival. Where this velocity is not obtained, through deposition of sediment or for any other reason, the supply of oxygen to some or even all parts of the gravel will be too low to permit survival."

"Deposition of sediments on sockeye spawning grounds can reduce the survival rate of eggs and alevins being reared in the gravel. The reduction in survival is in proportion to the reduction of flow of water through the gravel, which in turn varies with the

concentration of sediment and the sediment particle sizes. For a given concentration of sediment the finer particles in the size range tested were more effective in reducing percolation than the coarser particles. Reductions in survival are caused by insufficient supply of oxygen and by smothering of eggs with sediment. Depositions of sediment early in the incubation of eggs can be more injurious to survival than depositions close to the hatching period. This is believed to be due principally to the ability of alevins to improve or change their environment by body movements."

Campbell (1954) planted 100 eggs in gravel in a hatching basket in the Powder River, Oregon, below a gold dredging operation. Another 100-egg lot was planted in a clear tributary. Turbidity in the Powder River ranged from 1,000 to 2,500 ppm. All the eggs in the silty river died within a 6-day period, while total mortality in the 20-day test period in the clean tributary totaled but six percent.

What at first appeared to be an exception to the well-established fact that large quantities of silt are destructive to eggs in gravel was reported by Foskett (1958). Both the Shumahalt and Machmell rivers, British Columbia, contain large runs of sockeye salmon and yet carry heavy loads of glacial silt. Analysis of the situation, however, revealed that spawning occurs during heavy rainfall which reduces the concentration of silt and flushes out the spawning gravels. In addition, the fry emerge from the redds in the spring before the glaciers begin melting and deposit silt.

In recent years Canadian fisheries biologists at the Nanaimo Biological Station, British Columbia, have shed much light on some of the problems of sediment and egg survival. Wickett (1954) reviewed the early work on the subject of the requirements and consumption of oxygen by fish eggs and conducted experiments on the dissolved oxygen consumption of chum salmon eggs under controlled conditions. He concluded that the amount of dissolved oxygen supplied to the eggs in water depends upon both the volume of water flowing over the eggs in a given time and upon the dissolved oxygen content of that water.

Wickett found low dissolved oxygen values beneath consolidated and silted gravel of a side channel of Nile Creek, British Columbia. Washing the streambed by hosing increased both dissolved oxygen content and velocity of the water through the gravel.

Alderdice, Wickett, and Brett (1958) conducted further experiments on the dissolved oxygen requirements of chum salmon eggs and showed that critical levels of dissolved oxygen range from about one part per million in the early developmental stages to over seven parts per million shortly before hatching. Alderdice and Wickett (1958) experimented with the effect of carbon dioxide upon the ability of chum salmon eggs to utilize dissolved oxygen and found that as carbon dioxide concentrations were increased, oxygen utilization by the eggs declined. "Mortality (of eggs) appears to be a function of the inhibition of oxygen uptake by carbon dioxide, resulting in a deceleration of metabolic rate which ultimately is lethal if the inhibiting influence is prolonged."

Presumably, carbon dioxide build-up may occur outside of the egg capsule when sediment deposits on the bottom of a stream reduce the rate of subsurface flow in the redd to the point where waste products of the egg are not carried away as fast as they are being produced.

The Canadians have designed tools to measure the rate of water flow and dissolved oxygen concentrations within the spawning gravels (Wickett, 1954; Terhune, 1958; and Pollard, 1955). A similar device has been developed by the U. S. Fish and Wildlife Service (Gangmark and Bakkala, 1958). These are invaluable tools to those investigating the effects of sediment upon eggs or the gravel.

The general conclusion we reach from reviewing the considerable efforts of a number of competent investigators is that the effects of sediment upon alevins and especially eggs of salmonids can be and probably often is disastrous. Even moderate deposition is detrimental. Sedimentation is probably one of the most important factors limiting the natural reproduction of salmonids in streams, and certainly every effort must be made to prevent it.

INFLUENCES OF SEDIMENT UPON BOTTOM ORGANISMS

A tremendous number and variety of living organisms inhabit the bottoms of streams and rivers. Bacteria, algae, protozoa, and other lower forms thrive there and are basic components of the ecological community. They play important roles in the food chains converting inorganic nutrients to fish populations utilized by man. Quantitative studies of the effects of inorganic sediment upon the entire stream community were not apparent during our review of the literature. Most investigators have directed their attention toward certain groups of recognized importance.

Ellis (1931a, p. 17), reporting on investigations in the upper Mississippi River, stated that:

> ". . . Soil experts of the Department of Agriculture have shown recently that the silt now carried by the Mississippi River greatly exceeds in volume that which was carried by this same river only a few years ago, . . . The silting-in overwhelms the bottom fauna faster than it is able to adjust itself, with a result that many species are being eliminated or greatly reduced in numbers. As a complicating factor the erosion-silt suspension, which is almost collodial in nature, carries down with it when settling out partly decomposed organic waste which has reached the river through municipal sewage and other sources."

In a later report of the mussel situation on the Mississippi, Tennessee, and Ohio rivers, Ellis (1931b, p. 10) reported that:

> "Erosion silt is destroying a large portion of the mussel population in various streams by directly smothering the animals in localities where a thick deposit of mud is formed; by smothering young mussels even where the adults can maintain themselves; and by blanketing the sewage and other organic material which in turn produces an oxygen want that lowers the oxygen content of the water to the detriment of those species requiring well-aerated water . . ."

Sumner and Smith (1939), during an investigation of the effects of hydraulic mining on aquatic life of the Yuba and American rivers in California, collected a series of bottom samples in tributaries with different amounts of silt on the bottom. These authors report (page 27)

that ". . . production in silted areas in Yuba tributaries is but 63 per-cent of that in the clean, while silted American River tributaries produce only 41 per cent as much as the unsilted areas." A summary of the data is presented.

Tebo (1955 and 1957) reported on one phase of the watershed studies being done on the Coweeta Experimental Forest in North Carolina. During a 9-month period, 109 square-foot bottom samples were collected from Shope Creek, immediately above and below the mouth of a tributary draining a logged watershed. Data were analyzed statistically. During the period of sand and silt accumulation in the affected section, there was a statistically significant reduction of bottom organisms below the mouth of the logged watershed. Flooding removed the accumulation of sand and silt, and further reduced the bottom organisms in the silted area to 7.3 per square foot, as compared with 25.5 per square foot at the unsilted station. The bottom fauna rapidly recovered after the flood had exposed clean gravel and rubble.

Some preliminary figures on the effects of a placer mining operation on the physical, chemical, and biological features of Seigel Creek, Idaho, were presented by Casey (1959). A pre-dredging study showed that the bottom fauna population was approximately equal in all three study sections: above, in, and below the area to be dredged. Twelve bottom samples were taken in each of the three sections. Dredging started in May, 1958; by July of the same year the stream section at the dredge site and for about one-quarter mile below was completely silted over and almost devoid of aquatic organisms. Several samples contained no organisms. The section about one mile below the dredge showed over a 50 percent reduction. There was no obvious or consistent evidence that any one type of aquatic organism was more intolerant of siltation than any other type.

A similar reduction of bottom fauna was caused by waste water from a gravel washing operation entering the South Fork Chehalis River, Washington (Ziebell, 1957). A sample above the gravel operation contained 173 organisms per square foot. Only 32 and 4 per square foot were found in two samples 100 yards below the discharge. The 32 represented the best existing bottom condition in a "flushed-out" portion of the stream. A sample four miles downstream, where siltation was less evident, showed 113 per square foot. Improved conditions were found six and one-half miles downstream, revealing a total of 177 fish food organisms per square foot.

Ziebell and Knox (1957) investigated the effects of another gravel washing operation on aquatic life; this time the Wynooche River, Washington. Results of bottom samples collected below the gravel operation revealed reductions of 75 percent at points 200 yards and 0.3 miles downstream, and 85 percent at a station 1.7 miles below the discharge.

Silt from a gravel washing plant drastically reduced bottom organisms of Cold Creek and the Truckee River, California, according to Cordone and Pennoyer (1960). Reductions of over 90 percent occurred immediately below the outfall, and a reduction of over 75 percent was noted more than ten miles downstream.

Bachmann (1958) found a statistically significant decrease in volume of bottom fauna in an Idaho trout stream receiving silt from logging

road construction. Wustenberg (1954) found that silting in small Oregon trout streams from logging operations seriously reduced trout food organisms.

During an information-gathering survey of the Klamath River, California, and its tributaries, Taft and Shapovalov (1935) collected a series of bottom samples to obtain some idea of the relative quantity of bottom foods produced by the different streams. Forty-eight square-foot samples were taken. In a discussion of mining silt pollution, they concluded (page 16), "Whenever a series of quantitive bottom samples was taken in one stream or in a series of similar streams during the summer, the average number of food organisms in the one square-foot samples was *always* less in mined areas than in non-mined areas." Data are presented for the East Fork Scott River, where above a source of silt discharge the mean of three samples showed 249 bottom organisms in comparison with that of 36 for three samples in the affected area.

During the winter of 1957, silt from a hard-rock mining operation for molybdenum polluted Moore Creek in California. Bottom organisms from six square feet were collected both above and below the discharge point. A total of 434 bottom organisms was found in the clear water compared to only 32 collected from the silted area.

As reported by Wilson (1957), "Bartsch and Schilpp (1953) reported on sand processing wastes from a glass sand corporation in West Virginia as affecting a small tributary of the Potomac River. They concluded that the differences in production of plants and animals in affected and unaffected parts of the river are due principally to increased turbidity and solids deposition."

Reports published by the Oregon State Game Commission, *et al.* (1955) and Wilson (1957) summarized the results of extensive collections of bottom organisms above and below gold dredge operations on the Powder River. During siltation, production of fish-food organisms dropped to almost nil in the zone of heaviest pollution. Between 15 and 20 miles of the river were heavily silted. In about one year after the dredge closed operations, there was a remarkable recovery of bottom life. Silt was flushed from the pools and riffles by freshets and bottom organisms increased eight- to ten-fold in weight per unit of bottom area.

The effects of silt from the construction of Granby Dam on the Colorado River, Colorado, were reported by Eustis and Hillen (1954). They observed that flows below the dam from September, 1949, to April, 1952, were not sufficient to dislodge and carry away sediment in the streambed.

> "Stream-bottom samples were taken in 1949, 1950, and 1951. These revealed that a marked change in species of insects present occurred as a result of the deposition and accumulation of sediment. Aquatic insects, typical of the clean rubble bottom formerly existing, became much less prevalent; sediment-loving, burrowing organisms increased in number. This represented a distinct loss in trout foods. The caddisfly larvae and nymphs of several species of stoneflies and Mayflies which tended to disappear were to be preferred, because of their greater size and their accessibility, to the tiny midge larvae or 'bloodworms' which replaced them."

In summary, we can only conclude that there is overwhelming evidence that the deposition of sediment in streams can and often has destroyed insect and mussel populations. Much of the available information has been gathered during pollution investigations and is limited because of the small number of samples taken. It would appear, however, that those who report on the problem are unanimously in agreement that it is a serious one.

Significance of Substrate Type

A knowledge of the ecology of stream insects is helpful in understanding how silt influences production of bottom fauna. One of the more detailed ecological studies was made by Sprules (1947) in Algonquin Park, Ontario. Certain of his conclusions (pages 72 and 73) are pertinent to an understanding of silt and bottom fauna interrelationships:

> "The insect population [of streams] was reduced in areas where the bottom was scoured by a severe freshet. The reduction resulted from the loss of individuals which were dislodged and swept downstream by the current and the elimination of others through molar action. The effect of the freshet was minimized in areas where the bottom was relatively stable and composed of large particles which afforded shelter."
>
> "A variation in the number of species and number of individuals was found associated with different types of bottom in a restricted section of the stream. Rocky riffles were the most productive, followed in order by gravel, muck, and sand bottoms. The diversity of the fauna found on any particular type of bottom was related to the variety of utilizable microhabitats associated with the bottom type. It has been suggested that the number of insects present in any area is related to the habitable surface area of bottom particles exposed to the water."
>
> "The quantitative and qualitative distribution of insects observed in streams results from the complex interaction of many environmental factors, of which temperature, nature and configuration of the bottom particles, and rate of flow are of fundamental importance."

The importance of bottom materials to production of aquatic invertebrates is described by Smith and Moyle (1944, p 145):

> "The most important single factor affecting the bottom fauna production of streams is the physical nature of the bottom. Rubble is the most productive type. Such a bottom is fairly stable, has an abundance of small interstices to provide shelter for bottom organizms, and presents a large surface for the growth of microscopic plants that are the basic food of most smaller aquatic animals. Food production decreases as the particles become larger or smaller than rubble size and is poorest on bedrock and fine sand . . . Muck, being an organic soil, tends to be more fertile than fine-grained inorganic soils and may in some instances exceed the production on rubble."

Many studies have been made on the productivity of the various stream bottom types. In general, these have shown that insect production is higher in rubble and decreases as the substrate becomes composed of finer materials. Organic silt often contains tremendous numbers of organisms many of which are not readily available as trout foods. One such study on a Colorado trout stream was conducted by Pennak and Van Gerpen (1947). They refer to a number of other such studies in their report. No attempt was made to review these publications, with the exception of one by Tarzwell (1937).

During a stream improvement experiment on several Michigan trout streams, Tarzwell collected a series of 447 bottom samples. He compared the production of different bottom types and found that, "The data show that the sand areas produce the fewest organisms. If sand is given the population rating on 1, the relative productivity of the other bottom types was found to be as follows: marl, 6; fine gravel, 9; sand and silt, 10.5; gravel and sand, 12; sand, silt and debris, 13; gravel and silt, 14; *Chara* and silt, 27; *Potamogeton pectinatus*, 28; rubble, 29; coarse gravel, 32; *Chara*, 35; mucky areas, 35; medium gravel, 36; *Potamogeton filiformis*, 43; gravel and rubble, 53; sand and gravel with plants, 67; muck, sand and plants, 67; moss on fine gravel, 89; moss on coarse gravel, 111; moss on gravel and rubble, 140; *Vallisneria*, 159; *Ranunculus*, 194; Watercress, 301; and Elodea, 452."

The fact that insects are less abundant on sand bottoms than on gravel and less abundant on gravel than on rubble, has been adequately reported. The processes of erosion greatly increase the relative proportion of finer materials in stream bottom, and of course the deposition of mining debris or gravel plant waste accomplishes the same thing in a more startling and accelerated fashion. To us, there would appear to be adequate evidence that increasing the amount of fine material in the bottom of streams will eventually result in declining bottom fauna.

Sampling Problems

Most evaluations of the effects of silt pollution on bottom fauna have entailed the use of the Surber square-foot sampler as the collecting device. The advantages and disadvantages of this sampler have been described by Leonard (1939), Usinger and Needham (1954), and Needham and Usinger (1956). Using this tool, it was demonstrated conclusively that large numbers of samples are required to provide significant figures on total numbers and weights.

To attain such significant figures at the 95 percent level of confidence, Needham and Usinger determined that 194 samples were required for an estimation of total wet weight, and 73 samples needed for an estimation of total numbers of bottom organisms. However, only two or three samples were needed, again at the 95 percent level of confidence, to insure that at least one member of each of the commonest genera of bottom insects would be present. A comparison was made of samples taken with the Surber sampler with samples collected alongside in a buried tray on an intermittent stream. It was found that the Surber sampler captured about one-fourth of the total numbers of organisms and three-fourths of the different kinds of bottom organisms.

In a study of the Logan River, Utah, Hales and Sigler (1954) found that from 21 to 715 samples were required to estimate mean number, and 8 to 1,068 for mean volume of bottom organisms in a series of stream sections with 95 percent confidence of being right two-thirds of the time.

Many of the results of silt pollution studies are based on relatively few samples taken usually at a station above the silt source and a series taken at progressive downstream stations. The only studies we have reviewed that were evaluated statistically were those by Tebo (1955) and Bachmann (1958). The question arises, what reliance can be placed on the usual small number of bottom samples taken in a silt pollution survey?

Gaufin, Harris, and Walter (1956) presented a statistical criterion for evaluating the efficiency of different sampling devices currently in use. Random collections were made with a special long-handled dip strainer in marginal areas, with the Ekman dredge in the pools, and with the Surber sampler in the riffle areas. Three samples contained, on the average, at least half and in some cases two-thirds of the species observed in ten samples, and an average set of five samples yielded over eighty percent of all species observed. As many as 10 to 15 percent of species were not collected until at least eight samples were taken. Bottom forms are far from randomly distributed, and the authors suggest that bottom types to be sampled must be carefully selected if a small number of samples are expected to present a comprehensive picture of the fauna.

Allen (1959) presented a clear and valuable analysis of the factors affecting the distribution of stream bottom animals in New Zealand streams. After analysis of stream bottom samples Allen concludes, "A much smaller range of variation between samples occurs when a series is taken at places selected by eye to be as similar as possible . . . The coefficient of variation (standard deviation as a proportion of the mean) in a series of samples selected for uniformity is generally found to be about 0.2, while in gridded or randomized series within a fairly uniform area it is about 0.4 to 0.5. This increased variability is clearly due to environmental features."

It appears to us that the biologist faced with even a normal amount of pollution work cannot often collect and sort enough samples to make very accurate estimates of the standing crops of bottom organisms in the stream. This does not mean that he should give up bottom sampling, but rather that he probably will have to select his samples from areas that, before the pollution, were as similar as possible. Depth, velocity, and substrate type appear to be the significant features. This was done by Cordone and Pennoyer (1960) on Cold Creek and the Truckee River, California, and is the method used to some degree by most pollution investigators. Random sampling has achieved more respect than it deserves in this situation.

In selecting sample sites, care must be taken to select not only those that are similar, but also to not limit sampling to the areas where water velocity is great enough to prevent sediment deposition or wash it away once it has been deposited. If this is not done, the tests will minimize

the effects of sediment. Transects across similar riffles above and below the sediment source are suggested. Sampling devices must of course, be the most efficient available for the particular habitat sampled.

Importance of Bottom Organisms

There is no doubt that substantial quantities of inorganic sediment entering a flowing stream can seriously reduce the abundance of bottom-dwelling invertebrates; but, what effect does this have on fish production?

Trout food habit studies in stream situations have consistently shown the dependence of trout on aquatic invertebrates, particularly insects. At times terrestrial organisms play a significant role in trout diet, but under normal circumstances the bulk of the trout's diet consists of aquatic forms. Maciolek and Needham (1952) and other workers have established that trout feed on aquatic invertebrates year around, even during winter months at high elevations.

Poor production, growth, and condition of trout populations have been ascribed to poor food supply by many investigators. Most of the statements are of a general nature based on field experience and unpublished data. Leonard (1948), writing of conditions in Michigan, states, "The food supply is, more frequently than any other, the limiting factor in our waters. We have unmistakable evidence, acquired over many years and from a wide variety of lakes and streams, that an inadequate food supply is the most common cause of poor fishing quality, in lakes and streams alike."

A number of investigators have substantiated in the literature correlations among fish growth, condition, and abundance of bottom organisms. Only a few are mentioned here.

Ellis and Gowing (1957) studied bottom fauna production and the food habits and coefficient of condition of brown trout in Houghton Creek, Michigan. The abstract of this report is as follows:

> "Field study revealed great differences in the biological productivity of two adjacent areas of a Michigan trout stream resultng from the entrance of domestic sewage into the stream between the two areas. Monthly samples were collected from the two areas to determine the seasonal cycles in abundance of bottom fauna, feeding habits of the trout, and coefficient of condition of the brown trout. In the less productive area upstream, a paucity of food of aquatic origin caused a sharp decline in condition of the fish, a reduction in the quantity of food per stomach, and a shift to a diet containing a considerable portion of terrestrial organisms. In the more productive area downstream (which, throughout the year, had a greater volume of bottom fauna than the unproductive area) trout maintained a significantly higher and much less variable coefficient of condition, their stomachs contained more food in midsummer and did not show the increase in terrestrial foods."

Cooper (1953) found an apparent correlation between high condition factor and growth of eastern brook trout in three Michigan streams. In one stream he found indications that a low population of bottom or-

ganisms was a contributing factor in slow growth of the trout. Temperature data were also correlated with growth and condition, but did not explain the differences in growth noted in the one stream.

Brown (1946) found that brown trout exhibited an annual cycle of growth directly proportional to condition when reared in a laboratory under constant conditions of food, light, and temperature. Cooper and Benson (1951) demonstrated this cycle for brown and eastern brook trout, and Went and Frost (1942) also demonstrated it for brown trout.

Benson (1954) investigated the eastern brook trout of the Pigeon River, Michigan, and collected data which suggested a close relationship among periodicity of growth, condition, and mean volume of stomach contents. His work led him to suggest that growth rate depends upon optimum temperatures and on the abundance of food during the period of optimum temperatures. Allen (1940) found a close correspondence between the amount of bottom organisms in the stomach and the rate at which the fish is growing. Powell (1958), in a comparison of conditions above and below a power reservoir, found a correlation between the weight of bottom fauna and weight of brown trout stomach contents.

Allen (1951) found a close correlation between growth of brown trout and weight of food content in stomachs. He also found (pages 217 and 218) that, "Comparison between the zones [of the Horokiwi stream] suggests that the food supply tends to limit the production of trout, since as the pressure on the food supply increases the actual density of the bottom fauna decreases, and the proportion of the food drawn from it and suitable for growth also decreases." Decreases in the growth rate of trout following floods were attributable to destruction of bottom fauna.

A brief summary of this section can be made in three statements. First, there is abundant evidence that deposition of inorganic sediment will damage and reduce bottom fauna. Second, such reduction will in many cases deleteriously affect salmonid populations. Third, with care such reduction can be measured. These facts lead us to the conclusion that investigation of the bottom fauna is probably one of the most significant approaches that can be made in the detection and measurement of sediment problems.

INFLUENCES OF SEDIMENT UPON AQUATIC PLANTS

All natural-flowing waters are thought to contain at least some algae. The amounts vary tremendously with conditions. Lackey (1944, p. 236) found enough blue-green and green algae to support a large population of lower animals in the bottom of a rivulet six feet from its source; a spring in the side of a clay bank. Algae is commonly considered as the very basis of the food chain, and there can be no doubt that the effects of sediment upon it are of critical importance to the entire stream community.

Sediment is believed to destroy algae by molar action, by simply covering the bottom of the stream with a blanket of silt or by shutting off the light needed for photosynthesis. The effects are probably combined and therefore obscured. Inorganic sediment may occasionally carry nutrient materials, which further complicates the picture because these can be directly used by plants provided the turbidity itself does not destroy them.

Tarzwell and Gaufin (1953, pp. 6-7) have this to say about such situations:

> "Eroded materials also cause turbidity which affects productivity and water uses. Turbidity decreases light penetration and thereby limits the growth of phytoplankton and other aquatic plants which are of outstanding importance as a basic food for aquatic animals and as a producer of oxygen by photosynthesis. The photosynthetic activity of aquatic plants plays an important part in stream reaeration and in the natural purification process. Although turbidity prevents or limits algal growth, it does not eliminate the bacterial action which breaks down organic wastes. Thus, turbid waters may transport the by-products of bacterial action on organic wastes and the effluents of sewage treatment plants considerable distances before they are utilized. When the water clears due to impoundment or other causes so that the phytoplankton can grow, these fertilizing materials are utilized and may produce troublesome blooms, or taste and odor problems far from the source of pollution.
>
> "Soil washings from eroded areas are usually infertile and generally reduce productivity by choking or covering densely populated rubble gravel riffles, and covering rich bottom deposits. Washings, from fertile areas, where accelerated erosion is just beginning, or from rich well-fertilized agricultural areas, carry a great deal of nutrient materials into lakes and streams and increase productivity. This fertilizing effect may be so great that nuisance blooms of algae may develop each year such as those that occur in many Iowa lakes. These blooms become especially troublesome when domestic sewage is also added to the water. Further, in some areas, blooms of toxic algae are frequent and severe."

One perplexing problem has been to determine the effects on aquatic plants of turbidity caused by sediment in streams. Corfitzen (1939) studied the interaction of silt, light, and plant growth. He noticed an absence of algae in silt-carrying canals and attributed this to lack of sunlight rather than erosive action of the silt.

A literature search by Corfitzen revealed that in green plants the greatest absorption of light takes place when light wave length is less than 5,000 Angstrom units. Absorption increases as wave length decreases. Green leaves also utilize light in a small band in the red end of the spectrum between 6,500 and 6,700 Angstrom units.

Passing a light beam through a glass tube with suspended silt resulted in turbidity measurements. A photoelectric cell and microammeter registered the intensity. Greatest loss in intensity was due to light absorption by silt, with some additional loss by reflection and refraction.

It was found that blue light and other colors with wave lengths shorter than 0.00004912 cm. promote the growth of green plants. Thus, any silt concentration which absorbs blue light completely, absorbs all rays promoting plant growth. Based on the data collected, a curve was constructed which permitted a determination of the amount of silt required to completely destroy all green plant growth at any given depth.

Ellis (1936) made over 5,000 determinations of water carrying erosion silt, and found that the penetration of light into inland streams and rivers was being reduced at an alarming rate.

Phinney (1959) explored two general statements often used to describe the relationship between turbidity and sediment to photosynthesis. First—that as turbidity increases, the rate of photosynthesis decreases. Second—that sedimentation will reduce the photosynthetic rate of aquatic plants, because the sediment acts as a physical barrier preventing the free exchange of gases necessary for their survival. Phinney pointed out that, while these generalizations were true, they do not help much in solving our problems. Most research being done on the subject will result in the same general conclusions, unless biologists are careful to control and measure all the factors that affect the photosynthetic process.

During experimental work on photosynthesis—temperature, carbon dioxide concentration, and other factors must be controlled or carefully measured. The measurement of light reaching the plant chlorophyll is in itself a very difficult problem because of the scattering and diffusion of the light waves after they once enter the water. Phinney was critical of the methods now in use. He made a plea for sound research that will determine not just that turbidity decreases photosynthetic rate but rather the mechanics of how, why, to what degree, and under what circumstances this happens. He stated that research on the problem must consider (1) the metabolic status of the population (production and use of CO_2 and O_2), (2) the light transmitting qualities of the medium, and (3) the characteristics of the suspensoids and the color-controlling light transmission.

The complexity of measuring the effects of turbidity on aquatic plants should not discourage the biologist investigating the problems, for often the effects are very dramatic. Cordone and Pennoyer (1960) found that an abundant population of algal pads of the genus *Nostoc* was virtually destroyed by sediment discharged into the Truckee River, California.

Storms usually increase the turbidity of streams, and man's activities increase and prolong the period when light penetration is lessened. The question of the effects of relatively short periods of turbidity needs much study. Short-term discharges of sediment may do little visible damage to fishes, bottom fauna, or fish eggs, but may interrupt the entire biological complex through effects on algae.

INFLUENCES OF SEDIMENT UPON CHEMICAL AND PHYSICAL CHARACTERISTICS

Ellis (1936) outlined the important ways in which sediment affects the chemical and physical characteristics of the environment. He described changes in turbidity and light penetration in a number of streams where silt load had increased as a result of erosion. In addition he found that rates of heat transmission and heat radiation in waters carrying erosion silt were essentially the same as those for distilled water when the samples were constantly agitated. If the samples were undisturbed, the stratification of silt interfered with heat transmission and produced a skew lag in the warming and cooling curves. Regarding

changes in chemistry, Ellis found, through chemical determinations, that erosion silt does not materially alter the salt complex or the amount of electrolytes in river waters. He found that the specific conductance of river water fell after heavy rains despite great increases in the erosion silt load. Measurements in the Mississippi River demonstrated that available mineral salts, light penetration, and plankton were all reduced after rains or high water.

Ellis found that organic particles and other substances in the river are carried to the bottom as silt settles out. Often these substances are incompletely decomposed, so that large demands are made on the dissolved oxygen concentration of the river and noxious compounds are formed in these mud deposits. Field investigations were verified with laboratory experiments that also demonstrated that disturbances in pH and carbonate balances were also sustained over a much longer period when organic material was carried down by erosion silt than when deposited with sand.

Our review has turned up no work on the subject as extensive as that done by Ellis. Several authors have reported briefly on temperatures, dissolved oxygen, and pH during sediment pollution investigations.

Ziebell and Knox (1957) found no differences between dissolved oxygen and pH values above and below a source of siltation from a gravel washing plant. Casey (1959) also found no change in dissolved oxygen and pH below an active placer dredging operation in Idaho, but did find that water temperatures below the dredged area were one to two degrees higher than in the clear water above the dredge. A number of other silt pollution studies included measurements of dissolved oxygen, and pH above and below a silt discharge. None showed significant changes.

When organic materials enter the stream along with silt, such as is the case with logging debris, then changes in water chemistry, particularly reduced dissolved oxygen, can be expected. This has been recorded on numerous occasions during field investigations of logging pollution in the north-coastal counties of California.

The combination of silt and organic matter in a stream seriously complicates normal aeration processes as pointed out by Dunham (1958). Following field observations on Indian Creek, California, plus a review of Phelps (1944), he outlined the problem as follows:

> "Occasionally in turbid streams there is another very subtle factor called benthal decomposition which helps to significantly reduce the amount of dissolved oxygen at a critical time in the spring and summer months. If large amounts of organic material are brought into a stream during the runoff period, some portion of this material will be deposited in the bottom of pools and other areas of low velocity. During other periods of the year a part of the normal pollutional load carried by a stream will settle out and be deposited on the stream bottom. If these settled materials are accumulated in relatively large amounts they are recognized as sludge beds. If the stream continues to carry silt, it will also be deposited in these areas of low velocity and cover the organic material previously deposited forming a benthal deposit. This organic material will decompose slowly by an anaerobic process—a process which does not require oxygen. The end products of this

process will decompose farther in the presence of oxygen and actually use dissolved oxygen in the water. As the spring temperatures rise and the flow decreases, the organic material under the silt and sand begins to decompose at an increased rate. The end products of this decomposition, such as hydrogen sulphide, ammonia, iron, methane gas, carbon dioxide, and hydrogen, are soluble in water and gradually diffuse upward through the overlying silt and sand.

"At the surface of this bottom mud, the bacteria living in the water utilize these materials in an aerobic process which takes oxygen from the stream. This oxygen demand on the stream may be present over a long section of stream. It comes at a critical time when temperatures may be high, stream flows low, and when the stream is carrying an existing pollutional load which also demands oxygen. If the stream has a poor ability to recover from low dissolved oxygen conditions, benthal decomposition will make the situation even worse because it usually extends over an appreciable length of stream.

"Decomposition of benthal deposits has its greatest effect on the stream in a limited zone at the surface of the bottom materials. This zone will have the greatest concentration of substances such as hydrogen sulphide, ammonia, and carbon dioxide which are harmful to many organisms, and it will have the lowest concentration of dissolved oxygen. The presence of decomposing benthal deposits may be a limiting factor in some areas which could otherwise produce important food organisms. Consider even a riffle where anaerobic decomposition is taking place under and around the rocks, and suppose the stream has near-critical dissolved oxygen levels at times. The further decomposition of the materials resulting from anaerobic decomposition may take enough oxygen from the micro-habitat under and around rocks to be a significant factor limiting the distribution of aquatic organisms in certain instances."

The recent use of rivers to discharge atomic wastes places the problem in a somewhat different and even more serious light. Lackey, Morgan, and Hart (1959) reported on a series of experiments testing the ability of sediment of different sizes to settle blooms of *Golenkinia* and *Euglena* and to absorb and settle out radioactive substances. Sand, muck, and clay all were quite effective in settling the plankton.

In a stream polluted with atomic wastes, micro-organisms generally concentrate radioactive waste and they, being eaten by higher animals, transfer it along the food chain perhaps to man. The experiments demonstrated that the sediment itself absorbed radioactive ions and settled out.

INFLUENCES OF SEDIMENT UPON FISH HABITAT AND FISH POPULATIONS

There can be little doubt that numerous fisheries have been destroyed by erosion and sediment deposition during the periods of rapid development of this country and others. Unfortunately, only a few cases have been analyzed by fisheries workers.

The studies of Aitken (1936) and Trautman (1957) correlating great changes in the fish fauna of the mid-west, with increased erosion and sediment deposition, have been previously mentioned. Both report a change from what are considered game fishes to less desirable types.

Trautman, after reviewing the early Ohioana literature critically, concludes (page 28) that in 1750 there was little erosion in what is now Ohio. "The stream bottoms consisted almost entirely of clean sand, gravels, boulders, bedrock, and muck, peat, and other organic debris. The amount of clayey silt of stream and lake bottoms was negligible." Of the fish fauna he says (page 29), "The population of fishes were very great, especially of large fishes desired as human food." Trautman refers to pikes, walleyes, catfishes, buffalo fishes, suckers, drums, and sturgeons. He blames the decline of this fish population on a number of habitat changes wrought by man, the principal one being the introduction into the waters of large amounts of sediment (page 26):

> "Studies made since 1925 have proved that since then, if not before, soil suspended in water has been the most universal pollutant in Ohio and *the* one which has most drastically affected the fish fauna. Clayey soils, suspended in water, prohibited the proper penetration of light, thereby preventing development of the aquatic vegetation, of the food of fishes, of fish eggs, and of fry . . . Settling over the formerly clean bottoms, silt destroyed the habitat of those fish species requiring bottoms of sand, gravel, boulders, bedrock, or organic debris."

Wolf (1950) blames erosion and sediment deposition for the disappearance of the Atlantic salmon from many of its haunts around Lake Ontario. Eschmeyer (1954) mentioned the Whitewater River drainage in Minnesota, where by 1941 the original 150 miles of good trout stream were reduced to 60 miles by erosion.

Sediment problems in California rivers received some attention during the days of intense hydraulic mining for gold (1850-1900). Sediment loads were so heavy that farm lands in the Sacramento Valley were covered with soil and sand washed into the American and Yuba rivers. King salmon runs were at least temporarily destroyed and many miles of streams rendered unfit for trout (Sumner and Smith, 1939).

Sumner and Smith seined in the muddy sections of two tributaries of Yuba River, California, taking no trout whatsoever. Turbidity was attributed to the washings of pulverized ore from hard-rock gold mines. In one stream there was the possibility of toxicity from a cyanide flotation process. In a stream where muddiness occurred only once a week and lasted but a few hours, trout could still be found. The authors concluded, ". . . this survey, as well as other observations, shows conclusively that very heavy continuous silting will greatly reduce, if not completely eliminate, salmon or trout: In the Yuba River at Washington, to cite one good case, a pool was seen completely filled in with fine silt so that there was no place for a fish to hide. When this happens to long stretches of stream, game fish will be driven out. Shelter is just as important as food."

Dredging and mining continue in the west and have been the subject of considerable investigation. Campbell (1953) described fish population studies on the Powder River, Oregon, in relation to siltation from

a gold dredger. Samples were collected with an electroshocker during and following cessation of dredging. Although data were not given, the report states that sport fish did exist prior to operations in the silted zone. "Results of fish population studies in the various zones of pollution in Powder River indicated a complete alteration of the population from sport fish [rainbow trout and whitefish] above all major sources of pollution to rough fish [squawfish, suckers, etc.] in the zone of pollution and recovery. Although the desirable fish-food organisms gradually returned and conditions at North Powder were satisfactory for sport fish at the time of the survey, rough fish persisted. It is probable that under conditions of greater stream flow, the effects of the dredge wastes will persist farther downstream." The silted area was finally rotenoned to remove rough fish and then planted with trout. Creel census indicates that a sport fishery was successfully reestablished (Wilson, 1957).

According to Casey (1959), the fish population of Seigel Creek, Idaho, prior to operation of a placer dredge, was approximately the same in sections above, below, and within the area to be dredged. Fishes present were sculpin, dace, mountain suckers, mountain whitefish, and cutthroat, rainbow, and eastern brook trout. Population studies made at the end of about two months of operation showed no fish in the dredged section and a dominant rough fish population "below." Species composition above the silted area remained about the same.

Studies by Bachmann (1958) showed no changes in trout populations in a silted section of a northern Idaho trout stream. Direct disturbance of the stream was not great, however, and came from installation of culverts at road crossings, rechannelization of 1,000 feet of stream, and some log skidding in the streambed. Sampling difficulties prevented accurate comparisons.

Wustenberg (1954) reported that cutthroat trout populations were eliminated from three small streams crossed by tractor logging. The major source of silt was believed due to road building rather than the actual logged areas. A further note on the status of these trout populations appeared in the Annual Report for 1954 of the Oregon State Game Commission (1955, p. 216):

> "A tributary stream, previously reported as being one in which 'cat logging' eliminated the trout population, was found to again possess fish in the area which was barren a year earlier. Such a finding suggests that practices presently regarded as extremely destructive may be more temporary than heretofore suspected."

Seamans (1959, p. 21) reports that the lower section of the Saco River in New Hampshire supported one of the three best large brook trout fisheries shortly after the turn of the century. His observations suggest that the decline may well have been the result of sedimentation. The bottom of the stream is now shifting sand which has reduced shelter to a minimum.

During the winter of 1957, finely ground rock waste from a molybdenum mine polluted Moore Creek in California. Sampling with an electric shocker revealed a healthy population of native rainbow trout above the pollution, but only three pale-colored, emaciated fingerlings were caught with equal effort in the polluted section.

Cordone and Pennoyer (1960) reported on the extensive sedimentation of the Truckee River and Cold Creek in California by a gravel washing operation. Using similar "above and below" sampling with an electric shocker, they found a reduced trout population in the zone affected by sediment.

An excellent study of the effects of sediment upon the habitat and subsequent survival of planted Atlantic salmon fingerlings was made by McCrimmon (1954). From 1944 to 1949, he studied the survival and distribution of planted Atlantic salmon fry in Duffin Creek, a tributary of Lake Ontario. Fish populations in 19 experimental sections were assessed by use of the "one-man" hand seine.

Various factors which might influence survival were studied quantitatively. These included temperature, turbidity, predation, shelter, bottom sedimentation, shade, abnormal water flow, and food. McCrimmon concluded that the degree of bottom sedimentation determined the amount of shelter offered and this in turn determined the extent of predation. Clearing of woodlands for agriculture had resulted in extensive erosion in the watershed.

Bottom sedimentation was measured by means of small glass collectors placed in riffle areas under standard conditions for two weeks at a time. Material collected was air-dried for 24 hours at 100 degrees C. and then measured. A detailed explanation of mechanisms of sedimentation versus fish was presented (pages 396 and 398):

> "It has been shown in a previous section that the shelter offered by shallow gravelly riffle areas was the only satisfactory habitat for the high survival of planted fry in all streams. In the general description of the relative extent of sedimentation over the stream system, the criterion employed was the degree to which these gravelly riffle areas had become sedimented. Areas typed as "unsedimented" were those in which the spaces around the gravel and rubble were not filled in by sediment and hence offered the shelter required by the planted fry. The degree of bottom sedimentation played an important part in influencing the survival and distribution of the planted salmon.
>
> "As the amount of sedimentation of the stream bottom increased from the 'unsedimented' to 'heavily sedimented' condition, the apertures and spaces around the gravel, rubble and other irregularities even in the riffle areas became filled with sediment, until the protective cover offered to the small frys became low, resulting in a high salmon mortality. Thus the amount of sedimentation in the riffle areas largely determined the survival of salmon over the stream system.
>
> "It was shown that the survival of the small fry in the pools was low, largely because the absence of suitable shelter for the young salmon resulted in predation by certain species of fish. This lack of shelter was directly caused by the deposition of sediment in the pools sufficiently great to cover generally the gravel and rubble, and fill in the spaces around stones, boulders, logs and the like, to an extent that they could not be utilized by the fry.
>
> "From these observations on the correlation of the degree of bottom sedimentation in the gravelly riffle areas with the percentage survival of underyearling salmon, it may be concluded that the

effect of sedimentation was to destroy the shelter offered by the riffle areas which was needed for the survival of the salmon fry during and following planting. Sedimentation in the pools resulted in a low survival of fry even in stream sections where the riffle areas were free of sediment and provided excellent habitat for young salmon.

"Since the survival studies show that, once the salmon population had become established in the stream as fry and underyearlings, further mortality until the following autumn as yearlings was very low, it would seem that bottom sedimentation did not cause any appreciable mortality of the larger salmon. However, the inability of most of the tributary stream sections with high underyearling survivals to support the same number of salmon in their pools as yearling fish may be attributed largely to sedimentation."

Our own observations in California lead us to believe that shelter may be the factor limiting the numbers of trout growing to catchable size in many small streams. Even though abundant fingerlings are produced and riffle areas are kept clean by current velocity, sediment deposited in pools and runs fills in the spaces between boulders and rubble, reducing shelter for trout to a minimum. Extensive experience in sampling small trout streams on the west slope of the Sierra Nevada leads us to generalize that, all other things being equal, streams with clean rubble bottoms have large trout populations and streams with bottoms containing much sand or decomposed granite contain fewer catchable-sized fish.

SEDIMENT STANDARDS

An important tool in the pollution control programs of recent years has been the setting of "standards" of water quality of streams and rivers receiving waste discharges. Obviously sediment discharge is pollution. It is deleterious and usually caused by the activities of man.

Sediment standards are difficult to set and would be meaningful only if based upon thorough studies that allow accurate prediction of sedimentation rates, turbidities, and subsequent biological effects. Cooper (1956) appears to have done this on the Horsefly River in British Columbia.

Following a very thorough analysis of possible silt pollution from a placer mining operation, he arrived at the following recommendations for protection of sockeye spawning in the Horsefly River, British Columbia:

1. No placer mining operations be permitted in the stream bed or in any tributary stream beds.
2. No placer mining operations be permitted adjacent to the river or any of its tributaries without provision of settling basins to clarify all sediment-carrying waters by sedimentation and, if necessary, by filtration.
3. All suspended sediment in the effluent from such basins should be less than 0.1 mm. in diameter, and during the period July 1 to April 1, the turbidity of the effluent should be less than 25 ppm.

4. Any settled materials removed from the ponds during periodic clean-outs must be disposed of on land where they cannot be washed into the river or its tributaries.

Ellis (1937) suggested that if conditions even approximating those when erosion was checked by forest and grassland are to be restored, ". . . the silt load of these streams should be reduced so that the millionth intensity level would not be less than 5 meters, . . ." The millionth intensity level is the depth at which light is reduced to one millionth of its intensity at the surface.

Ellis (1944) restated this conviction and added to it, in an effort to prevent direct damage to the gills and delicate exposed structure of fishes, mollusks, and insects:

> "From the standpoint of aquatic life therefore all particulate matter introduced by man of a hardness of one or greater should be so finely pulverized that it would pass through a 1,000 mesh screen, and should be so diluted that the resultant turbidity would not reduce the millionth intensity level to less than 5 meters. The quantity should be controlled so that the stream could carry the powder away without blanketing the bottom to the depth of more than one quarter of an inch."

Tarzwell (1957) felt that it was not possible to establish numerical criteria for settleable solids which are applicable over wide areas. He maintained that the amount of damage done will vary with the character of the stream and its substrate. He felt that criteria should be established to protect environmental conditions but they will vary from stream to stream, depending on local conditions. He discussed some tentative criteria based on measures of light penetration (page 253):

> "Turbidity standards must be somewhat local in their application as they will depend on the area and type of stream. It is possible to set up relatively simple turbidity standards which can be readily checked for compliance by field tests. Turbidity standards might state that a certain percentage of the incident light at the surface shall reach a stated depth between 11:00 A.M. and 1:00 P.M. The depth selected would depend on the depth to which the regulatory agency felt the photosynthetic zone should extend. Different types of water differ in their capacities to absorb light. Water transparency is affected by the suspended matter, including the plankton, and by stain or color. In water of the clarity of usual municipal supplies, 9.5 percent of the solar energy present at the surface reaches a depth of 6 feet . . . the limit for growth for the higher aquatic plants lies between 2.5 and 3.5 percent of the total surface energy at bottom depth, but that it rapidly declines below 4 percent where severe etiolation occurs in submerged seed plants. There is some evidence that certain algae can grow at levels of 1 percent of the incident light, but it is not definitely known how much light is required for them to produce more oxygen by photosynthesis than they use in their respiration. While criteria will vary with the area they can be kept relatively simple. For example, a criterion for a particular area might state—under conditions of brilliant sunlight at or near noon 4 percent of surface incident light

shall reach a depth of 6 feet. Incident light and light at any given depth can be readily read by means of photometer fitted for underwater use."

Wilson (1957) stated that, ". . . rather than to propose arbitrary criteria either for turbidity or settleable solids, some percentage increase above normal low flow concentrations should be established. This would take into consideration differences in watershed and stream or reservoir characteristics."

The Aquatic Life Advisory Committee of the Ohio River Valley Water Sanitation Commission (1956) did not establish requirements governing settleable solids. The seriousness of the silt pollution problem was presented in detail, but due to a lack of exact information, no valid criteria were formulated.

Waste discharge requirements commonly set on an operation likely to discharge sediment into trout, salmon or steelhead waters tributary to the Central Valley of California usually contain the following clauses adopted by the Central Valley Water Pollution Control Board:

Any waste discharged into the waters of ___ __ _ Creek:

1. Shall not cause an increase in the natural turbidity during the period from May 1 to November 1 of each year.
2. Shall not contain deleterious substances in amounts which would be toxic or harmful to animal or aquatic life.
3. Shall not produce silt or gravel deposits.
4. Shall not cause the dissolved oxygen content of receiving waters to fall below 7.0 ppm.

Protection of the streams from damage by excess turbidity during the period November 2 to April 31 must depend upon investigations to show that requirement Number 2 was violated. Certainly no standards are by themselves going to prevent damage from sediment; but equipped with a general set like this, a knowledge of what has been learned in the past by others, and some biological investigation on the stream, the biologist should be able to greatly reduce it.

LONG-TERM SILTATION RESEARCH

Among fisheries scientists, there is an increasing awareness of the need for basic, long-term investigations on the influences of erosion and siltation on fish production. To our knowledge, there are at least four such projects now in existence. All of these are concerned with the relationships between logging operations and production of salmon or trout in streams. Siltation is but one, although probably the most important, of the means by which logging and its associated works act to modify the stream habitat.

Four small trout streams in northern Idaho are under investigation by the Idaho Cooperative Wildlife Research Unit of the College of Forestry, University of Idaho. Trout species include both cutthroat and eastern brook. Studies of these streams prior to road construction and actual logging have been completed (Oien, 1957). The second phase of the study covered the influence of logging road construction on the physical, chemical, and biological characters of the disturbed stream

(Bachmann, 1958). The final phase now in progress will cover the effects of actual logging in the area.

Another long-range project designed to critically evaluate the influences of logging is now under way on four salmon streams in Alaska. It was initiated in 1949 by the Alaska Forest Research Center of the U. S. Forest Service and will cover at least a 15-year period. A summary of the program and of the Center's first five years of work prior to logging was published by James (1956) and Anderson and James (1957). Data of great interest on natural changes in stream channel topography, sedimentation, and movements of bottom material are presented in the former paper. The need for biological investigation brought about a cooperative research program starting in 1956 between the Center and the Fisheries Research Institute of the University of Washington under contract to the U. S. Fish and Wildlife Service (Sheridan and McNeil, 1960).

For the past seven years the Department of Zoology of the University of California at Berkeley has studied the fish populations, fish habitat, and related matters on Sagehen Creek, California. These studies will be extended to include the effects of stream flow and sedimentation on fish populations (Anderson, 1958). Evaluations will cover the effects of forest, brushland, and other land treatments on streamflow, sedimentation, and fish habitat and populations. Trout species include brown, rainbow, and eastern brook.

The final, known long-term research project on the influences of logging is proceeding under direction of the Oregon Cooperative Wildlife Research Unit, Oregon State College. The results of preliminary studies were presented by Wustenberg (1954). Current plans call for an extended study of pre-logging conditions on trout streams.

SUMMARY

Almost all of the investigations we have reviewed on the effects of sediment on the aquatic life of flowing waters have been done on streams inhabited by trout and salmon. Only historical changes and the work of Ellis (1931a) are available to evaluate the warm waters.

There is abundant evidence that sediment is detrimental to aquatic life in salmon and trout streams. The adult fishes themselves can apparently stand normal high concentrations without harm, but deposition of sediments on the bottom of the stream will reduce the survival of eggs and alevins, reduce aquatic insect fauna, and destory needed shelter. There can scarcely be any doubt that prolonged turbidity of any great degree is also harmful.

The question, "How much sediment is harmful?" has not yet been answered since most workers have failed to measure the amounts of sediment. The Aquatic Life Advisory Committee of the Ohio River Valley Water Sanitation Commission (1956) reviewed the problem and reached the following conclusion:

> ". . . only a small amount of sand or silt shifting in and around the gravel of the bottom eliminates much of the area suitable for the attachment or hiding of the aquatic insects and drastically reduces the total production of these forms. Small amounts of sand, not discernable by casual inspection but evident only on close ex-

amination of the bottom materials, can bring about significant changes.

"To the best of our knowledge adequate data are not available on the amounts of inorganic materials which can be added to a stream without significant harm to its productive capacity. . ."

This certainly agrees with our own observations. Field investigations with electric sampling gear in the Sierra Nevada over the past years have led us to develop the maxim, "Clean stream bottoms mean good trout populations." By "clean" we mean lacking much sand.

Many of the sediment problems reported in the literature are the result of large-scale discharges of sediment from gravel washing or mining operations. These are often spectacular but probably less important than the gradual deposition being caused by erosion.

The increasing activity of man on our mountain watersheds in California is resulting in obviously increased erosion and sediment deposition. Our failure to recognize that even small amounts of sediment may be harmful may well result in gradual destruction of the majority of our streams, while we work feverishly to solve more obvious and spectacular problems.

We have been impressed by two facts. *First*, there has been sufficient work done to establish the fact that sediment is harmful to trout and salmon streams; the only references found to the contrary (Ward 1938a and 1938b) have been adequately criticized. *Second*, our experience in the Sierra Nevada indicates that the bulk of the damage there is unnecessary. It can be prevented with known land use methods, often with little or no additional expense. Much of it is the result of carelessness.

More than anything else we need to develop a philosophy of land husbandry that will avoid the creation of untreated and running sores on the earth's surface. Man must acquire a responsibilty to future generations that matches the power he has gained through the development of heavy machinery.

Our observations in the field and our review of the existing literature leads us to the unshakable conclusion that unless this can be done many of our trout streams will be destroyed by the deposition of sediment.

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BOOK REVIEWS

Recreational Use of Wild Lands

By C. Frank Brockman; McGraw-Hill Book Company, Inc., New York, 1959; 346 pp., illus., $8.50.

This book published as one of the American Forestry Series is the first of its kind devoted solely to the subject of wild lands recreation. It contains a well organized summary of the principles and background information. This volume is destined to be an important reference work for professionals dealing in recreational planning and administration or management. In will, no doubt, also serve as a basic college text in this field.

The text is written in a compact, concise style with adequate use of illustrations and tables throughout. Each chapter is followed by a brief summary as well as an excellent reference list. This latter item in itself is of great value since it brings together under one subject heading, the principle literature on wild lands recreation.

Drawing on many years of experience in both the National Park Service and U.S. Forest Service, the author provides the reader with a broad prospective background for a better understanding of the recreational values of different types of public lands. Individual chapters are devoted to background history and problems of the wildlands administered as national parks, national forests and state parks. Unfortunately, there is no discussion whatsoever, of development and use of privately-owned wild lands for recreational purposes. One interesting chapter reviews the principal recreational areas established in other countries of the world.

Perhaps the most thought provoking chapters are those dealing with economic values, and administration-management problems of wild lands. Those who have had to establish economic values on various wild land uses know that benefits of such areas transcend a dollar value. When people seek the recreational opportunities in an area, they desire more than food, lodging, transportation and the like even though these are what they paid for. Author Brockman concludes. "In effect, any economic recreational survey will indicate only the monetary return derived from minimum secondary values; primary values cannot be evaluated economically."

Although of general interest, this book is primarily of value to those who work directly in various aspects of the recreational field. This definitely includes those individuals responsible for administration and management of our fish and wildlife resources.—*Willis A. Evans, California Department of Fish and Game.*

This Land of Ours—Community and Conservation Projects for Citizens

By Alice Harvey Hubbard; The Macmillan Company, New York, 1960; 272 pp., $4.95.

This is the book for those who wish ideas on worthwhile community conservation projects at the local level. Author Hubbard's premise is that "the world is moved not only the mighty shoves of the heroes but also by the aggregate of the tiny pushes of each honest worker." In other words, "grass roots" leadership practiced by small groups represents a tremendous potential for conservation achievement.

The volume covers such matters as, guarding our heritage of natural beauty, roadside beautification, garden recreational facilities, sanctuaries, forest and watershed problems, community improvement, and educational programs with specific examples of how these problems may be solved. Many actual projects are fully described.

Although directed primarily at the women of America for action through garden clubs, youth groups and service clubs, it is a source of inspiration for any group seriously interested in protecting our natural resources. The professional conservation worker will find it useful as a reference aid for ideas in developing local projects. Apathy is recognized as the major problem in most communities.

The pattern to follow in carrying out successful projects is described in a 12-point summary:

1. A public spirited individual or group recognizes a need and determines to do something about it.

2. An analysis is made of the problem, with the advice of experts sought where necessary.
3. Teamwork is employed.
4. A plan of action is worked out.
5. A program of education is undertaken.
6. The project is made the responsibility of the whole community.
7. Where and how to raise the necessary money is undertaken.
8. Successful groups work in harmony with public officials.
9. Contests are a means of creating interest.
10. Interest is sustained by publicity and progress reports.
11. Provision is made for the maintenance and future security of the project.
12. Enthusiasm is the main factor for success.

The writing is well done, and holds one's interest despite a total lack of illustrations.

An interesting new idea attributed to a Dr. Fosberg is described. It consists of hiring an official in a community government known as a "community ecologist" whose function is to forsee the ecological consequences of projects and activities sponsored or sanctioned by the community.

The book is sprinkled with many fragments of sound conservation doctrine such as:

> "Whatever its faults, the American way of life has brought us the greatest productivity and the highest standard of living of any people in the world. But let us not forget that neither would have been possible without our wealth of natural resources. With "progress" nibbling away at the good earth from every angle and our population increasing steadily, there is little doubt that conservation will become more and more important as the years go by. Consequently we cannot start too early to train our children to cope with the resource problems they will have to face."

—*Willis A. Evans, California Department of Fish and Game.*

Trout Farming

By David B. Greenberg; Chilton Company—Book Division, Philadelphia and New York, 1960, XVI + 197 pp., 154 illus., $12.

The prospective trout farmer or the man already in the business may be somewhat disappointed if he expects this book to be the complete answer to all the problems encountered in raising trout. Anyone seeking information on hatchery and rearing pond operations will find the material covered by "Trout Farming" is more general than specific.

However, Mr. Greenberg's book is excellent reading for its chapter on the historical background of artificial fish propagation, its interesting description of fish cultural activities in other countries, a chapter on some of the commercial marketing operations and its numerous black and white photographs and drawings on various phases of trout raising.

The book is divided into fourteen chapters, as follows: History of Artificial Fish Propagation; Future of the Trout Industry; Trout in the State of Nature; Something of the Anatomy, Physiology and Embryology of a Trout; Brood Trout and Stripping; The Incubation of Trout Eggs; In and about the Hatchery Building; Ponds and Raceways; Feeding; Sorting, Grading and Transporting; Your Own Trout Pond; Predators; Trout Diseases; Going Trout Farms and Their Marketing Methods. An appendix of useful information of measurements for drug and chemical treatments; a bibliography of fish cultural publications from France, Spain, Germany and Norway; periodicals containing most of the current information on trout culture and early American and English books on fish culture is also included.

The book begins by crediting the Chinese with discovering a method of aiding nature in the propagation of fish. Mr. Greenberg notes that mention is made in the works of a Chinese author, written about 2100 B.C., of laws regulating the time at which fish spawn should be taken.

Hatchery and rearing pond operations are described in chapters five through thirteen. Information in these chapters tells of methods of handling broodstock, both wild and domestic, and of spawning fish. Description of spawning methods used in other countries than the United States are interesting, but some of them would be of questionable value if used where a large number of eggs was taken. Also contained

in these chapters is information on incubation of eggs and types of equipment used for incubation. Various kinds of troughs, tanks, ponds and screening devices are described. There is a chapter on feeding methods and one on grading and transplanting fish with various grading devices and planting tanks described.

The author's chapter on trout diseases is good as far as it goes, but it contains no description of trout parasites and their control—important information to a trout farmer.

An excellent word of advice to the reader by Mr. Greenberg, is a statement in his chapter on trout ponds. He says, "Complete data is lacking on trout kept in ponds, because no two of these are alike in respect to depth, surface area, temperature, topography, altitude, latitude, source of water, quality of water and natural supply of fish food. In time to come, research will produce more general rules to help the trout pond owner, and it is well to keep abreast of the data furnished by your own state conservation department for the newest developments."

Such advice would apply not only to pond culture, but to all phases of trout propagation.—*David Ward, California Department of Fish and Game.*

The Trumpeter Swan. Its History, Habits and Population in the United States

By Winston E. Banko; United States Fish and Wildlife Service, Washington, D.C., 1960, North American Fauna. No. 63, 214 pp., $1.

This is another excellent monograph in the series, North American Fauna.

One of America's most spectacular waterfowl, the trumpeter swan, was at such a precariously low population level in the early part of the century that the eminent ornithologist, Edward Howe Forbush, lamented in 1912; "The trumpeter has succumbed to incessant persecution in all parts of its range and its total extinction is now only a matter of years—its trumpetings will soon be heard no more."

Mr. Banko's account begins with the primitive history of the world's largest swan and brings us up to 1957 at which time the species appears to have become reestablished to the saturation point within the present breeding and wintering range in the United States. Further increase of the trumpeter within our borders will apparently depend upon the success of transplanting breeding stock to new locations.

The book contains chapters on distribution, habitat, life cycle, population and management. The section on population dynamics should be of exceptional interest and value to wild life technicians because of the comparative ease with which the conspicuous trumpeter swans can be censused and studied within their restricted range.

This reviewer is particularly impressed with the excellence of the numerous illustrations, especially the flight pictures reproduced on the frontispiece and on page 75.

This book is highly recommended as an important contribution to the library of game manager and conservationist.—*William Anderson, California Department of Fish and Game.*

The Craft of Technical Writing

By Daniel Marder; The Macmillan Company, New York, 1960; xiv plus 400 pp., $5.

When first scanning this book, I was unimpressed. In the introduction the author writes, "The students should realize at the outset that writing is a craft to be mastered rather than a science to be learned." He ignores the innate quality which distinguishes the art of prose from the dull tedium laboriously inscribed by the "hack".

Within the introduction and later at length, Marder emphasizes the need for exact communication and the precise use of words. But he writes, "The technical writer introduces his subject and tells what purpose he has for *speaking* about it." (The italics are mine.)

The author states that the first drafts should be as full of details as possible; that it is much easier to draw a line through details which seem unnecessary later on than to reopen paragraphs and put in more detail. This may be true, but must be modified from an editor's point of view in which he finds that most authors decry the use of the blue line through their chosen words and phrases. Deletion by the editor is amputation in the eyes of the author.

Marder, in discussing the nature of language declares, "No matter what a tree is called or how defined, it remains what it is. Only the words which stand for the things are defined." (I don't think that Joyce Kilmer would like this expose!)

This quotation is an indication of how the author uses pronouns and the word "thing" as crutches.

These criticisms of the author's style in writing become subordinate to the value that his book assumes when it is read and analyzed. Each point of the written language is thoroughly dissected and its purpose carefully disclosed. These points range from the period, comma, semicolon, etc., through grammar and rhetoric, sentence structure, style, composition, to organization. It is written in an interesting manner with liberal use of examples. In addition, the book contains a short section on the scientific method and how it is related to the report—whether that report is administrative, a progress report, or a technical publication. Within this section there is a discourse on the types of audience and how that will influence the writing of the report. In short, there is much to be gained within the pages of the book whether the reader is a student, professional technician or scientist, or anyone else who may take up a pen or pound a typewriter.

If all would-be authors heeded the suggestions of this book the task of the editor would be simplified. Furthermore, the application of the principles delineated by Marder would ease the task of writing and contribute to a feeling of self-satisfaction in those now troubled by report writing. The small investment of this book will be amply repaid if its contents are digested and constructively used.—*Merton N. Rosen, California Department of Fish and Game.*

Aquatic Plants of the Pacific Northwest with Vegetative Keys

By Albert N. Steward, La Rea Dennis, and Helen M. Gilkey; Oregon State College, Corvallis, 1960; 184 pp., 22 plates, $2.50.

This is an ideal book for the identification of aquatic plants. The text includes descriptions of mosses, liverworts, ferns, and the higher plants. The scope of the text includes Oregon, Washington, British Columbia, and Alaska. However, the geographic ranges for the individual plants are given and in many instances are noted to be cosmopolitan, or throughout the western United States.

The book has dichotomous keys for the plant families, the divisions and subdivisions. Leaves or other plant materials are used in the keys for identification. The illustrations are not numerous but are adequate for identification. The plates have from six to nine detail drawings of individual plants on them.

The descriptions of the individual species are short, but adequate. This is followed by habitat description and geographical distribution, both scientific and common names are provided.

The book will prove useful as a field guide for game biologists and fisheries biologists as it can be used throughout the year to identify plants found in an aquatic environment.

An adequate six page glossary is provided for those not acquainted with systematic botany terminology.—*William C. Johnson, California Department of Fish and Game.*

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STATE OF CALIFORNIA

FISH AND GAME COMMISSION

Notice is hereby given that the Fish and Game Commission shall meet on April 7, 1961, at 9.30 a.m., in the California State Building, First and Broadway, Los Angeles, California, to receive recommendations from its own officers and employees, from the Department of Fish and Game and other public agencies, from organizations of private citizens, and from any interested person as to what, if any, orders should be made relating to birds or mammals, or any species or variety thereof, in accordance with Section 206 of the Fish and Game Code.

FISH AND GAME COMMISSION
Wm. J. Harp
Assistant to the Commission

Notice is hereby given that the Fish and Game Commission shall meet on May 26, 1961, at 9.30 a.m., in the State Employment Building, 722 Capitol Avenue, Sacramento, California, to hear and consider any objections to its determinations or proposed orders in relation to birds and mammals for the 1961 hunting season, such determinations resulting from hearing held on April 7, 1961, commencing at 9.30 a.m. in the California State Building, Los Angeles. This notice is published in accordance with the provisions of Section 206 of the Fish and Game Code.

FISH AND GAME COMMISSION
Wm. J. Harp
Assistant to the Commission